THE HAWAIIAN
PLANTERS' RECORD

Vol. XXXVIII FOURTH QUARTER, 1934 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In this Issue:

Light Showers and Dew as a Source of Moisture for the Cane Plant:

Recent irrigation studies at Waialua Agricultural Company, under the authority of a cooperative project between that plantation and the Experiment Station, H.S.P.A., give additional evidence that light showers and dew falls may be of decided significance in the water economy of the cane plant.

Previous work with the same cane variety in tanks at Waipio gave similar results. This short paper summarizes these observations on the water-absorbing characteristics of the aerial parts of the cane plant and suggests additional work on this subject. A clear understanding of this important physiological characteristic is of great commercial as well as scientific interest.

Measures for the Control of Anomala Orientalis at the Oahu Sugar Company:

Extensive studies of *Anomala orientalis* populations at Oahu Sugar Company, Ltd., have been made by the plantation. Large-scale efforts in the artificial control of this insect, by many methods, have also been completed, some of which proved to be effective. Detailed data covering this work are given, which include procedures, materials and results.

Predisposing Factors in Pythium Root Rot:

No disease of sugar cane has been more obdurate than root rot. It has occurred in various parts of the world to bring about the decline of the cane variety known elsewhere as Bourbon, locally as Lahaina. Failures of this cane in some regions were reported as early as 1846; here the Lahaina variety began to fail before 1900 and by 1920 was being rapidly replaced by H 109.

Suspicious cases of failure of H 109 caused renewed interest in root rot studies, but such failures were found in general to be related to other causes.

High nitrogen fertilization was found to be a predisposing cause of severe root rot attack in susceptible varieties, and of slight attack in resistant canes.

Recently, canes ordinarily resistant have been found to suffer pronounced root injury from *Pythium,* in certain areas, in the absence of heavy phosphate fertilization. There are indications that there is sufficient available phosphate for growth, could the plants be kept free of *Pythium,* but not enough to throw the balance in favor of the cane when it is present.

This type of growth failure is discussed as another example of the destructive action of *Pythium* when the cane roots are preconditioned by sub-normal nutrition. The situation is further complicated by the occurrence of aluminum salts in high concentration in these soils, and no doubt aggravated by low temperatures and poor conditions of soil moisture.

The paper deals largely in a review of work elsewhere on *Pythium* fungi in relation to other crops and a comparative study is made between the findings of local workers and those of other investigators.

Light Showers and Dew as a Source of Moisture for the Cane Plant

By H. A. Wadsworth

It has long been recognized that a statement of the annual precipitation in an agricultural region is not a satisfactory basis for judging the local necessity of irrigation. Seasonal distribution is of greatest importance.

For deep-rooted crops the ideal distribution of rainfall has been described as a series of independent rains, each of sufficient duration to wet the soil to the depth of greatest root penetration with no losses by surface run-off. Rains of greater duration than this result in wetting the soil to greater depths than can be reached by the plant roots, while a series of light showers, although they may add up to an appreciable precipitation in a year, contribute little to the well-being of a deep-rooted crop. In some regions it is customary to estimate the effective rainfall by dividing the annual precipitation by two, assuming that half of the annual rainfall is unavailable for plant use because of surface run-off, excessive penetration, or surface evaporation.

Similar arguments have been advanced with respect to the requirements of the sugar cane plant and it has been said that showers of less than half an inch are negligible in the water economy of the plant. Here the assumption is made that the effect of such showers on a young field is minimized by the unavoidable losses through surface evaporation, while such showers on a field of big cane are insufficient to penetrate the trash blanket covering the soil.

The Local Situation

Sound as this argument may appear from acknowledged principles of soil physics and from previous studies with other plants, it does not seem to be in accord with many local observations upon sugar cane. A field on Maui produced a satisfactory yield of both cane and sugar with an irrigation interval, before harvest, of about 300 days. The showers during this period were described as being well distributed but too slight to affect the soil moisture content.

Moreover, field men have often observed the stimulating effects of rains too insufficient in amount to increase the moisture content of the soil upon which the cane was growing. In some cases heavy dew is mentioned as an aid in reviving cane which had shown the first signs of wilt.

More concrete evidence of the significance of light showers on cane growth is provided in the elaborate irrigation studies being conducted at the Waialua Agricultural Company under a cooperative agreement between that plantation and the Experiment Station, H.S.P.A. Swezey (7), representing the Experiment Station in this cooperation, reports as follows:

> During the past month the rates of cane growth have followed the conditions of weather (rainfall and dewfall) and soil moisture in the same way as reported two months ago. You will

note that I mention dewfall as a weather condition. It *is*, of course, a phase of daily weather but I wish particularly to refer to dewfalls and light rainfalls as they have been observed during the past month. (By light rainfalls I mean amounts of rain up to 0.20 or 0.30 inch per day.)

We have noted on several occasions that when the soil moisture has been approximately at or slightly below the wilting point there have occurred the heavy dewfalls or light rainfalls mentioned. The rate of growth at those times has not declined as was expected on account of the depleted soil moisture. Coincidental with the dew or light rainfall, we observed no increase in soil moisture.

One would not, I believe, expect a heavy dew to raise the moisture content of the soil. Also, the cane during the past month has closed in well and consequently light showers of rain are caught on the cane leaves and the soil receives no water. (A minimum of from 0.50 to 1.00 inch of rain is the smallest amount capable of penetrating the leaf screen and reaching the ground.)

The evidence seems to indicate that enough water is absorbed by the leaves or the bases of the leaves to keep the plants growing in spite of lack of sufficient moisture in the soil. . . .

Evidence From Other Stations

Although such light rains and dews have never before been considered as important supplements to irrigation, some academic aspects of the aerial absorption of moisture by plants have been reported in the literature.

Maximov (5) reviews the results of early workers in the field under the heading "Absorption of Water by the Aerial Organs of Plants." General as the title is, it is devoted largely to detailed work on the absorptive capacity of leaf tissue. Although some attention is given to epiphytes, no mention is made of the possibility of absorption through the nodal zones in the case of grasses.

In 1930 Hiltner (3) reported the results of a long series of experiments under the title, "Dew and Its Significance in Plant Growth." This author asserts in his summary that dew is an economically important meteorological factor, the influence of which in practical plant growth is unjustly neglected. Another significant statement is that with certain plants the moisture intake of the leaves may be substantial in amount in relation to the total moisture consumption of the plant.

However, Livingston (4) seems to feel that the effect of dew and light rains in the water economy of plants is due to the reduction of losses by transpiration and not to the actual absorption of water in significant amounts through leaf and stem surfaces.

It remained for Breazeale (1) to observe what appears to be an increase of soil moisture around the roots of a plant because of the discharge of water through the roots. Breazeale used corn growing in the experimental fields of the Arizona Station. Long brace roots which had just reached the soil surface but had not yet developed laterals were inserted into small glass jars, which were subsequently filled with dry soil. The opening was then sealed with a warm paraffin-beeswax mixture. An apron of oilcloth was provided as further protection. An increase in moisture content in the soil in the jar was usually noted; in cases where the roots in the jar approached the glass a small zone of moist soil could be detected even before the root appeared in view. Breazeale concludes that the root tip was exuding water which kept a moist zone of soil in front of and in direct contact with the elongating root.

Hendrickson and Veihmeyer (2) fail to substantiate the general application of this principle after a comprehensive series of greenhouse experiments with sunflowers and beans.

It is interesting to note, however, that Breazeale in his publications fails to note the effect of rain upon his small jars of dry soil containing the brace roots from the corn plants. Dr. O. C. Magistad,* who worked in close association with Breazeale, reports that a rain occurring during the time of observation increased the moisture content of the soil in the jar to such an extent that Breazeale suspected the adequacy of his seal. The similarity of this experience with that secured locally with sugar cane is suggestive.

Local Observations

Occasional references (6), (9), (8) in the local reports of studies in the relation of the sugar cane plant to moisture indicate that the sugar cane plant may have characteristics similar to Breazeale's corn. Remarkable gains in soil moisture during showers, either natural or artificial, have been experienced which can be accounted for only by, (1) assuming that the experimental technique was much poorer than it appeared, or (2) endowing the sugar cane plant with the capacity of absorbing large amounts of water in its aerial parts, the conveyance of this water into the root zone and its discharge into the soil mass.

Unwilling as the observers were to admit the first of these alternatives, it appeared necessary in view of the inconclusive nature of the evidence. The temporary curtailment of such studies has made it impossible to continue the work.

However, the field work at Waialua makes it necessary that additional consideration be given to this aspect of the general problem, if a true understanding is desired.

The following summary of the experimental evidence as to the water-absorbing capacity of sugar cane is given to focus attention once more upon an aspect of sugar cane physiology which is not only of great scientific interest but of considerable commercial value as well.

The tank equipment at Waipio has been often described (6). In brief, it consisted of a series of large cylindrical tanks, each holding about a ton of soil and so placed that it might be quickly and rather accurately weighed. Germinated eyes of H 109 cane were planted in each tank on April 5, 1929, and the tanks irrigated to maximum field capacity by the aid of a suspended balance.

When mature cane had formed, wooden covers were framed to fit the area between the rims of the tanks and the opening in the center, which was left for the development of the sticks. This opening was plugged with machinist's waste and this waste coated with paraffin. The spaces between the rims of the tanks and the wooden covers were caulked in the same way. It was assumed that such seals would protect the soil surfaces from evaporation as well as exclude rain, except that which might beat through the seal under a driving wind.

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The summer of 1929 was remarkably dry. No significant precipitation occurred until August 25, when the plants were about five months old. A shower of 0.58 inch on August 25 resulted in erratic increases in weight in most cases.

The increases in weight for the several tanks under the influence of the August shower are summarized in Table I.

TABLE I.

Increases in gross tank weights due to precipitation of 0.58 inch, August 25, 1929.

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	11	8	5
2	8	9	3
3	1	10	5
4	6	11	13
5	4	12	8
6	—2	13	—8
7	11	14	4

The irregular gains in weight in most tanks were attributed to faulty seals and to lack of precision in the weighing equipment. It is assumed that the balance was reliable to the nearest five pounds.

A second heavy rain of 3.00 inches on September 24 and 25, 1929, ruled out the possibility of inaccurate weighings and concentrated attention on the nature of the seals. The results of the September rain are given in Table II.

TABLE II.

Increases in gross tank weights due to precipitation of 3.00 inches, September 24 and 25, 1929.

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	79	8	109
2	75	9	90
3	53	10	107
4	84	11	93
5	86	12	71
6	52	13	50
7	51	14	72

Such tremendous gains were beyond any possible error in the scales and since the main problem demanded precise soil moisture control, every effort was expended to improve the nature of the seal. Oilcloth aprons were fixed to each tank, this material being sealed to the mature sticks with a mixture of petrolatum and paraffin and the junction subsequently painted with shellac.

Gains in weight persisted after these precautions. A shower of 1.79 inches on October 5, 1929, resulted in gains in weight as reported in Table III.

TABLE III.

Increases in gross tank weights due to precipitation of 1.79 inches, October 5, 1929.

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	20	8	45
2	44	9	32
3	5	10	37
4	36	11	18
5	34	12	36
6	31	13	35
7	16	14	40

Still dissatisfied with the nature of the seals, a new procedure was devised which to all appearances would make the passage of water impossible. The new seal involved the use of a high-grade roofing asphalt and powdered resin. The material was melted over an open fire and poured over the wooden covers and waste plugs to a depth of about one and one-half inches. The hot mixture was brushed up onto the mature sticks coming through the seal, and over the edges of the tank.

The period from November 1 to 7, 1929, was particularly wet at Waipio, the tank farm rain gage indicating a total precipitation of 7.11 inches during the period. In spite of the character of the seals most of the tanks gained significantly in weight during this week of heavy precipitation. Gains in weights are shown in Table IV.

TABLE IV.

Increases in gross tank weights due to precipitation of 7.11 inches, November 1 to 7, 1929. (During this period the tanks were equipped with asphalt seals.)

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	47	8	—2
2	45	9	—3
3	23	10	11
4	52	11	99
5	22	12	79
6	32	13	36
7	29	14	20

Additional showers from December 10 to 17, 1929, increased the weight of all tanks except No. 9. The asphalt seals were still in place. Detailed gains are shown in Table V.

TABLE V.

Increases in gross tank weights due to precipitation of 3.29 inches, December 10 to 17, 1929. (Asphalt seals in place.)

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	16	8	55
2	30	9	—1
3	15	10	(see below)
4	24	11	37
5	35	12	30
6	9	13	11
7	15	14	17

In addition to these series of observations, in which all tanks were used under natural precipitation, other tests were made on selected tanks subjected to artificial showers.

Tank No. 8 was sealed with asphalt and resin on October 15. A stream of water from a garden hose was run over the seal for an hour after careful note had been made of the gross weight. A second careful weighing at the end of this treatment showed that no increase had occurred. Since the stream from the hose had been applied to the critical points in the seal, it was assumed that the seal was adequate against leak. However, when the hose was suspended above the plant and equipped with a sprinkler head so directed that the aerial parts were subjected to a continuous spray for one hour, a gain in weight of 16 pounds was noted.

Similar tests with Tank No. 8 were conducted on October 19 after additional asphalt had been applied and the seal tested. When the stream was applied to the aerial parts of the plant, a gain of 7 pounds was noted in the first hour, 9 pounds in the next 45 minutes and 6 pounds in the next 30 minutes, or a total gain of 22 pounds in 2 hours and 15 minutes.

A more conclusive demonstration was arranged on December 13. On this date the cover of Tank No. 10 was removed and soil samples taken from a vertical hole at three-inch intervals from the surface to the bottom of the tank. The surface of the soil was covered with oilcloth carefully cut to fit close to the edge of the tank and around the stool. Twenty-five pounds of technical plaster of Paris was spread over the oilcloth, making a layer about two inches thick. It was felt that a mechanical leak of water through the seal would be evidenced by the characteristic smooth surface-hardening of this material. The wooden cover was replaced, caulked and covered with the hot asphalt-resin mixture. A test of the efficacy of the seal after the manner described above showed no gain in weight which might be attributed to leak.

When the plant was sprinkled for four hours, a gain in weight of 71 pounds was noted.

Although the period from December 15 to 17 was one of high humidity and rainfall, the tank showed no further gain.

On removal of the top on December 17 the plaster of Paris was found to be uniformly hardened in a rough irregular surface as if it had hardened because of the saturated atmosphere in the tank. Two small spots, each about the size of a dime, were hardened with a smooth, slick surface as if a drop or two of liquid water had fallen on the light, fluffy surface prior to the general hardening.

Soil samples were again taken from a vertical hole driven into the soil at a point diametrically opposite the one previously used. Again three-inch increments were sampled.

Table VI gives the results of the two series of soil samples.

TABLE VI.

Moisture percentage at three-inch increments in Tank No. 10 before and after sprinkling.

Depth in Inches	Before Sprinkling	After Sprinkling
0-3	24.1	24.0
3-6	23.6	23.3
6-9	23.1	22.8
9-12	23.1	17.6
12-15	24.6	25.6
15-18	24.3	27.9
18-21	25.6	27.9
21-24	27.8	32.2
24-27	27.4	31.3
27-30	26.2	31.7
30-33	28.4	34.2
33-36	29.4	33.0
36-39	31.3	33.5
39-42	29.1	34.2
42-45	30.1	33.4
45-48	32.2	33.9
48-51	33.7	33.7
51-54	33.0	37.9

It would appear from these results that water had been admitted to the soil mass below the surface foot without wetting the surface foot. The evidence of the plaster of Paris seal supports this conclusion.

Interest in these results and a hope that these unsuspected physiological characteristics of the cane plant might be comprehensively studied, prompted the formation in April, 1930 of an Experiment Station project under the title "A Study of the Water Absorption Capacity of the Aerial Parts of the Cane Plant."

This project has contributed little to our present knowledge, although some progress was made as long as whole cane plants growing in soil under careful control were used. Some significant gains in weight were noted. The modification of the original plan involving primarily a study of the capacity of cane leaves to absorb water brought the project to an unofficial end in April, 1931.

Summary

This paper summarizes a long series of observations involving what appears to be an amazing capacity of the cane plant to absorb water through its aerial parts.

The problems involved are still unsolved and are of compelling scientific interest.

A current cooperative project involving the Experiment Station, H.S.P.A., and the Waialua Agricultural Company has recently added evidence to the general understanding. The comprehensive attack of this project needs additional information as to the physiological processes involved.

This note is prepared to summarize the evidence so far at hand and to suggest continued exploration in this new aspect of the water relations of sugar cane.

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Measures for the Control of *Anomala Orientalis* at the Oahu Sugar Company, Ltd.

By WILLIAM WOLTERS

INTRODUCTION

Records show that *Anomala orientalis,* a native insect of Japan and Korea, gained entrance into the Territory of Hawaii some time prior to 1908 but that it was not definitely identified until 1912 when grubs were found damaging some of the cane fields of Honolulu Plantation Company, whence they spread to the fields of the Oahu Sugar Company. Anomala developed into such a serious pest that the trustees of the Hawaiian Sugar Planters' Association sent Dr. F. A. G. Muir in March of 1913 to the Orient, Java and the Philippines in search of enemies of the Anomala beetle. Several beneficial insects were brought to the Territory and released on the affected plantations. *Scolia manilae* was the only one that took hold and became established in the fields.* It was discovered in the Philippines by Dr. Muir in 1915 and shipments were made of this valuable parasite in 1916 and 1917. Scolia soon had Anomala under control as was shown by the reduced numbers and slow spread of the beetle, until about 1930 when Anomala outbreaks were again noted in some fields of the Oahu Sugar Company. Anomala infestation spread causing more and greater damage while Scolia seemed to have lost control of the situation. The Oahu Sugar Company, seeing this condition, proceeded to take immediate action in formulating measures of control.

* A second parasite *Tiphia segregata*, introduced from the Philippines in 1917 by Dr. F. X. Williams and liberated at Oahu Sugar Co., Ltd., has recently been found established.

Measures of Control

This paper is based on the work done at the Oahu Sugar Company over a period of three years in which the agricultural department of the plantation took an active part in conducting tests in the field. Many suggestions from members of the Experiment Station H.S.P.A., and others were tried out and we appreciate their contributions. Methods of control, technique of methods and results of our control measures are herewith discussed. Our control measures are classified as follows:

I. Soil Fumigants
II. Contact Insecticides
III. Electricity and X-Rays
IV. Stomach Poisons
V. Plowing and Fallowing
VI. Minor Control Methods
VII. Parasitic and Insectivorous Agencies

The above list embraces chemical, physical and natural control measures that have been used on the plantation. Unfortunately we have no practical way of determining in advance the presence of Anomala grubs in the soil. Anomala damage can be detected only after the cane is several months old at which time cane growth is checked, a slight yellowing of the leaves occurs and a weakened stool condition manifests itself.

Excavation studies were conducted systematically in order to determine the effectiveness of the various control measures.

Bi-monthly excavation schedules have been maintained on infested fields during plowing and preparation for planting.

The results of these studies have given us indications of the habits, spread, and intensity of infestation of Anomala under various soil and climatic conditions, as well as the amount of parasitism by Scolia. The grub counts obtained by these excavation studies indicate the time when it is safe to plant following a heavy infestation prior to plowing.

Check excavations were made from time to time in fields of growing cane where infestation was in progress or had previously occurred.

I. Soil Fumigants:

Soil fumigants may give temporary relief but do not protect the soil against renewed infestation. The more toxic fumigants are generally expensive and are both difficult and dangerous to handle. The less toxic and cheaper fumigants are generally ineffective and are more expensive in the end. Heavier applications of less toxic fumigants are necessary to equal the killing powers of the more toxic ones. The soil fumigants used in field tests are as follows:

(a) Chloropicrin
(b) Carbon bisulfide
(c) Paradichlorobenzene

(a) *Chloropicrin* is sealed as a liquid in steel cylinders. It is the most toxic of commercial fumigants and, in liquid form, has a specific gravity of 1.6. It vaporizes immediately on coming in contact with the air. It is most difficult and dangerous to handle, especially in cane fields where the air circulation is poor. The liquid is applied to the soil by means of special injectors to a depth of 8 inches. The treated area must be immediately sealed with a tar paper mulch in order to prevent the escape of gas from the soil. It is necessary for the operatives to wear gas masks and under such conditions they are only able to work for ten minutes at a time. It is slow, tediously disagreeable and expensive work.

The gas spreads in all directions from the point of injection, filling up the air spaces within the soil. The gas lasts about 36 hours when the soil surface is sealed with tar paper. The efficiency of the gas depends upon the amount applied and the texture and moisture content of the soil. We have obtained a maximum efficiency of 96 per cent kill under favorable conditions. It is too expensive for general use but serves its purpose where large colonies of grubs concentrated within a small area are to be eradicated immediately.

Experimental plots were laid out in an Anomala-infested area of a 6-month-old H 109 plant field. These plots received 100- and 200-pound applications per acre of chloropicrin with and without tar paper seals. The most effective kill was obtained in plots receiving 200 pounds per acre sealed with tar paper. Cane damaged by this gas does not fully recover. Two hundred pounds of chloropicrin per acre without the tar paper seal did the greatest damage to the cane. Results in terms of Anomala killed by the gas are shown in the table below:

Pounds Chloropicrin per Acre	Per cent Kill
100 pounds—no paper seal	33 per cent
100 pounds—plus paper seal	56 per cent
200 pounds—no paper seal	52 per cent
200 pounds—plus paper seal	68 per cent

There were several fields of 6-month-old H 109 ratoon cane with scattered patches of badly damaged cane that needed immediate action to check further spread of the damage. Judging from the results of the tests previously mentioned, it was decided to apply 200 pounds of chloropicrin per acre under a tar paper seal. We obtained a 50 per cent kill on two mauka fields which had a relatively compact soil and a 95 per cent kill on a makai soil of a more friable texture.

(b) *Carbon bisulfide* is sold in iron drums. It is a colorless inflammable liquid which is poisonous and has a strong, disagreeable odor. It volatilizes into a brownish vapor. It can be poured into holes made in the soil but it is best applied by means of injectors. Since the vapors are heavier than air, it is unnecessary to seal the soil surface. Ten times as much carbon bisulfide as chloropicrin must be applied in order to approach the killing power of the latter. One thousand pounds of carbon bisulfide per acre were used in the tests in a 6-month-old plant field and a 6-month-old ratoon field. An excavation study was made of the test in the plant field and we obtained a 50 per cent kill. There was no apparent damage done to the cane by the carbon bisulfide.

(c) *Paradichlorobenzene* is a crystalline, granular compound which slowly volatilizes in the soil. The vapor from it, being heavier than air, diffuses downward and outward through the soil mass when it is placed several inches below the soil surface. The material is easily handled and the vapor then given off is harmless to human beings. Its cost is about one-half that of carbon bisulfide and one-fourth that of chloropicrin.

Holes, 4 to 5 inches deep, are punched in the soil by means of a one-half inch rod and spaced 15 inches apart alternately on either side of the cane row. One-quarter to one-half ounce per hole gives an application of from 200 to 400 pounds per acre. The holes are plugged with soil. A week is necessary before any results can be expected since the crystal volatilizes so slowly. Action stops temporarily after an irrigation and begins again when favorable soil conditions return. Small test plots were placed in the relatively heavy soil of a mauka field and in the friable soil of a makai field.

This fumigant is used in Australia against soil insects and it is said to cause no injury to cane. This checks with our own experience. It is, however, ineffective against the Anomala grub as shown by the results from a test made on the looser soil type.

	Per Cent Kill	
	10 Days After	20 Days After
Amount	Application	Application
200 pounds per acre	8.9 per cent	6.8 per cent
400 pounds per acre	6.2 per cent	5.5 per cent

II. Contact Insecticides:

We have found no contact insecticide that can be successfully used against the Anomala grub. We tried out two products, namely, (a) Derris or tuba root *(Derris elliptica)* and (b) Check Exterminator, a Chinese preparation.

(a) *Derris:* The following abstracts are taken from the U. S. Department of Agriculture, Washington, D. C., Miscellaneous Publication No. 120, April, 1923.

> Derris is a genus of tropical plants comprising about 40 species . . . . Rotenone is the most important insecticidal constituent of *chinensis* and *elliptica.* As a rule, dried *Derris elliptica* root of good grade contains from 2.5 to 6 per cent rotenone . . . . It is insoluble in water, readily soluble in chloroform, benzene and acetone and slightly soluble in ether, alcohol and oils . . . . Rotenone is both a contact and stomach insecticide and promises to be effective against a wide variety of insect pests . . . .

We received a carton of powdered Derris root from Derris, Inc., New York City, which contained 4 per cent rotenone. Quoting from Marshall Dill's (Pacific Coast representative of Derris, Inc.) circular:

> This type (Sarawak variety), which represents a toxicity of approximately 15 to 16 per cent Toxic Rosin, is the most efficient type of Derris in root form imported into the United States.

The following quotation is taken from an entomologist's report to Derris, Inc., dated November 13, 1933:

> The addition of Derris dust to the surface of the soil and watering would, I believe, not be very effective against any of these insects (Japanese beetle grubs and grubs of the taxus weevil). I also doubt very much whether it would be effective if it would be dug into the soil . . . . I believe, that Derris powder or its extracts would be of little use against grubs infesting any roots of sugar cane.

Commencing on December 14, 1932, we ran a test consisting of a series of three boxes containing six inches of soil each, into which we placed 50 medium-sized and 50 large-sized grubs to each box. Powdered Derris root was applied at the rate of 100, 150 and 200 pounds per acre respectively to the three boxes. The powder was worked into the top 2 inches of soil and a normal amount of water was applied. The boxes were screened to prevent outside infestation. Soil moisture was maintained at a normal figure. We examined the contents of the three boxes on February 20, 1933, after a run of two months. We were unable to determine definitely the mortality resulting from the treatments since many grubs probably completed their life cycle within the test period. We found three dead grubs, one in each box. Amount of application seems to have no bearing on the number of surviving grubs. There were 38 grubs in the 100-pound rate box, 43 grubs in the 150-pound rate box and 66 grubs in the 200-pound rate box.

(b) *Check Exterminator* is a combination contact insecticide and weak fumigant manufactured by Look Teong Kee of Honolulu. This insect exterminator has been successfully used on golf greens throughout Oahu against sowbugs, earthworms, etc. The manufacturer's agents asked permission to try out their product for killing Anomala grubs. We cooperated with them in some laboratory and field experiments. The first exterminator used was the type that drives insects out of the ground, similar to the kind used on golf greens, but it did not work on the grubs. This brand of exterminator was replaced by their most powerful Check Exterminator which was supposed to kill insects in place. This was used in the experiments described below.

Three one-line plots were placed alternately down a watercourse in an area badly damaged by Anomala. The plots were filled with irrigation water and while still full, Check Exterminator was sprinkled over the water at the rate of 6,000 pounds per acre. The water was vigorously agitated to get a uniform solution which was allowed to percolate into the soil. Excavations showed that the exterminator reached a depth of 18 inches below the bottom of the furrow, as indicated by the fumes in the soil. It did not penetrate the hard subsoil. Excavations were made from 5-foot sections of line equivalent to 25 square feet to a depth of 18 inches at intervals of 1 day, 2 days, 3 days, 1 week, 2 weeks and 4 weeks after application.

	Per Cent Kill for Each Period					
Intervals:	1 Day	2 Days	3 Days	1 Week	2 Weeks	4 Weeks
	0	0	6.2	4.8	0	0

The results show a very low per cent of kill, if we could prove to ourselves that the Check Exterminator really did kill the grubs.

This test was repeated under controlled conditions, using a wooden box 12 inches square and 18 inches deep. Ten large, healthy grubs were placed in each of three, six-inch layers of soil partitioned off by fine-mesh wire screens. Check Exterminator was applied in solution at the rate of 6,000 pounds per acre. Normal soil moisture was maintained. After 7 days the soil was removed and the grubs examined, but we recorded no mortality. We can safely conclude the Check Exterminator is of no avail and the price would not need to be considered.

III. Electricity and X-Rays:

An experiment was made to determine the effect of electricity on Anomala grubs. We wanted to find out whether grubs could be killed in the soil by electricity, since we had the opportunity of using an electric plow owned by one of the pineapple companies.

Grubs were exposed directly to the intense electric arc created by an A. C. current of low amperage and high voltage and died from the effect of burns. Then grubs were placed in a layer of moist soil (necessary to conduct a current) about two inches thick. One electrode was placed below the soil and one above the soil and an A. C. low amperage-high voltage current (varying from 10,000 to 25,000 volts) was passed through the soil. As long as the grubs remained within the soil they did not seem to be injured by the current, but as soon as they came in direct contact with the arc, they were burned by it. Our chief electrician coöperated by conducting the electrical phase of the test. These tests were repeated a number of times with the aforesaid results. The impossibility of deep penetration into the soil by an electric current apparently eliminates any ideas of practical field operation with the apparatus available at present.

It seemed a bit far fetched to consider X-rays as a possible means of killing grubs, but an experiment was made, nevertheless. Several large grubs were subjected to X-rays at full strength for two minutes which was the time limit in order to avoid strain on the X-ray tube. They became extremely antagonistical within five minutes after the exposure and proceeded to fight each other. They were alive several days later and seemed none the worse for their treatment.

IV. Stomach Poisons:

Lead arsenate, white arsenic and Derris root were the only materials under the above classification considered worthy of more extensive experimentation. Lead arsenate was used in the earlier experiments, and in the first lot of mud press-arsenic traps which are described later. The high cost of this material made its use on a field scale too expensive.

Derris has already been discussed under *Contact Insecticides* (a).

White arsenic (As_2O_3) was finally selected as offering the greatest promise of success and has been used in a number of ways. It is fully as effective as lead arsenate, and is far less costly. It is easily and firmly fixed by the soil and does not noticeably injure the cane, even after heavy applications to the soil. It is evidently effective for several crops since it does not leach out, which has been shown by soil analyses two years after an application. Care must be taken to protect the men handling it due to its poisonous composition. Whenever opera-

tives apply arsenic, they are required to wear standard respirators and to wash their hands thoroughly before eating and at the end of the day. It is the most effective chemical agency we have in the artificial control of Anomala from an economic standpoint. The arsenic program may be divided into the following phases of application:

(1) Mud Press-Arsenic Traps
(2) Broadcast in the Cane Furrows
    a. Mixed with mud press
    b. Alone
    c. Mixed with fertilizer
(3) Plowed into the Soil
    a. Alone
    b. Mixed with mud press
    c. Mixed with fertilizer
(4) Application of Mud Press-Arsenic Mixture to Ratoon Cane
(5) Application in Waterways

(1) *Mud Press-Arsenic Traps:*

Traps consisting of mud press sprinkled with arsenic, or mixed with it, were set out in piles along the edges of fields exposed to Anomala-infested areas. Mud press has a great attraction for the beetles as a material in which to lay eggs, and the young grubs feeding on the mud press are killed by the arsenic.

The first mixture was in the proportion of one ton of mud press to 100 pounds of lead arsenate. Shallow holes were dug six feet apart along the edges of two fields of one-year cane adjacent to, and on the leeward side of, two Anomala-infested fields which were being plowed. The traps were set out January 13, 1932, and a year later they were still intact and arsenic was present. C. E. Pemberton of the H.S.P.A. Experiment Station made periodic examinations of these traps but never found any live grubs in them although dead beetles were found from time to time, showing that they must have been active. Trials of arsenic treatments were extended gradually until we felt sure that they were producing results. More fields, similarly exposed, were treated in the same manner, but white arsenic was used in the mixture. These traps were set out as an insurance against possible infestation of the unaffected areas.

(2) *Broadcast in the Cane Furrows*—(a) *Mixed with Mud Press:*

The application of arsenic was continued on a larger scale and it was broadcast over the entire furrow.

Our first experience was in a field of 4-month-old plant cane. The Anomala grubs were doing considerable damage in scattered patches throughout a portion of the field. Light applications of arsenic, followed by a light blanket of mud press, with a second dressing of arsenic on top of the mud press, were made over the entire furrow in the infested spots. The grubs which were already in the soil probably were not affected by this treatment, but we felt certain that any new infestation would be greatly reduced as a result of the young grubs feeding

on arsenic-treated mud press. This method, however, is comparatively slow and relatively expensive for a general practice, and can be used only when mud press is available at the mill. The cane which had been damaged by the Anomala did not fully recover, but it improved a great deal as a result of the treatment. The field was harvested in March, 1934, and there is little or no evidence of Anomala damage in the first ratoon.

(2) *Broadcast in the Cane Furrow*—(b) *Alone:*

In a field of growing cane, it was found to be more feasible to broadcast white arsenic alone to the cane furrows or kokuas because of the cost of application of the mud press-arsenic mixture. Due to the nature of white arsenic, it was difficult to apply it in quantities less than 200 pounds per acre even when working under the best conditions. It is difficult to estimate the rate of application when arsenic is broadcast over furrows and kokuas in scattered and irregular patches.

One damaged field was treated by the above method in 1932 and four damaged fields in 1933. The damaged fields in 1934 were too heavily infested for the use of this spot method, and were plowed up.

When the infestation exceeds the limit of economical control by the spot method, then it becomes necessary to plow the entire field a number of times, during a fallow of several months' duration in order to eliminate Anomala (See V. *Plowing and Fallowing.*)

(2) *Broadcast in the Cane Furrow*—(c) *Mixed with Fertilizer:*

It was felt that ratoon fields showing indications of light Anomala infestation would benefit by a light application of arsenic to the entire field. It is impossible to make accurate applications of less than 300 pounds per acre in growing cane so as to cover the entire line, and this amount of arsenic per acre is more than is required under these conditions. Scolia do not seem to operate in cane after it is well closed in, but Anomala continue to operate. Arsenic would protect the field after Scolia ceased to function. Therefore, a method was sought by which white arsenic could be applied economically and in light amounts. This has been accomplished by mixing it with any dry fertilizer normally applied to the field. The Pacific Guano and Fertilizer Company makes arsenic-bearing mixtures according to requirements. The amount of arsenic applied per acre depends upon the fertilizer-arsenic mixture and the rate of fertilizer application. Fertilizer is applied in one application or in split applications to suit conditions. The men are protected with respirators and necessary precautions are taken in handling the mixture. The fertilizer-arsenic mixture is broadcast over the lines by hand. By applying arsenic in this manner, the rate of application is more uniform and there is a saving in the cost of the work. Several fields have received this treatment and the cane is in excellent condition with no outbreaks of Anomala.

(3) *Plowed Into the Soil*—(a) *Alone:*

One of our upland fields (Field "A")* was infested with Anomala grubs to

* For the purpose of this paper, certain fields are designated as "A", "B", "C", and "D".

the extent of making it necessary to plow. It was decided to try out a heavy application of arsenic plowed into the soil at the rate of one ton per acre. Three, one-third-acre plots were selected in parts of the field which had suffered the greatest damage. Prior to the application of arsenic, the field had been disc-plowed twice, deep-plowed once and disc-harrowed once. The three plots were disc-plowed twice and disc-harrowed once after the arsenic application. The arsenic was broadcast by hand on March 18 and the plots were planted on March 31, 1932. They received normal plantation cultivation, fertilization and irrigation.

This experiment is exceedingly interesting because we can closely follow up the effect of large quantities of arsenic on soil population, cane growth and yields over a long period of time. The first excavation and grub count to determine the effect of arsenic was made six months after application. One hundred square feet were excavated from each of the treated and untreated areas to include the kokuas and bottoms of the lines to a depth of 12 inches below the bottoms of lines. The results of this excavation showed an average difference of 87 per cent in Anomala grub population in the soil in favor of the arsenic treatment.

Excavation studies were made 25 months after the arsenic application to determine the continued effectiveness of arsenic on grubs. The field, meanwhile, had been harvested and ratooned. Excavations were made to a depth of 20 inches below the bottoms of the furrows and all grubs and insects present in the soil were counted. The greatest numbers of both, including Anomala in all stages of development, were found in the 0 to 10-inch layer followed by the second largest number in the kokuas and the smallest number in the 10- to 20-inch layer. There were 91 per cent less Anomala grubs in all stages in the arsenic plots.

We observed the effect of this heavy amount of arsenic on cane growth and color from time to time. The growth seemed about the same for the unaffected stools of cane in either plot. There were times when we thought the cane was greener in the arsenic plots but this may have been due to healthier growth. There was a noticeable difference in the stand of cane and at harvest time, at the age of 23.7 months, the arsenic plots outyielded the check plots by 10.16 tons of cane, equivalent to a 12 per cent increase.

(3) *Plowed Into the Soil*—(b) *Mixed with Mud Press:*

It is usually found that repeated plowing and harrowing during a fallow period of three to six months will practically eliminate Anomala from a heavily infested field. However, the grubs will sometimes persist despite this treatment, and arsenic treatment over a relatively large area becomes necessary.

Hand mixing mud press and arsenic for any large area is economically out of the question. Broadcasting in the open field is not to be recommended from the standpoint of the health of the men and also because it is impossible to make a uniform application, due to the nature of the compound. The cheapest and most feasible method is to mix the arsenic with the mud press and apply it mechanically. This is done as follows: In order to mix these materials, a platform was built over the mud press conveyor which is *outside* of the mill and fully protected to prevent escape of arsenic dust. A mechanical fertilizer-hopper was set up on the platform and a feed pipe was dropped from the hopper into the conveyor.

Mechanical drive is furnished by the shaft of the screw-conveyor. The arsenic flow is regulated by a feed control. It takes the mud press ten minutes to travel from the arsenic hopper to the discharge of the conveyor trough into the mud press car. The screw-conveyor gives the mud press and arsenic a thorough mixing during this period of time. This mixture is hauled to the fields in mud press cars and reloaded into mud press spreaders. After the mud press-arsenic mix has been applied to the field, it is plowed and harrowed into the soil a number of times to insure proper incorporation with the soil.

A 21.94-acre area in Field "B" was the first place to receive this treatment. Periodic excavations in this area had shown very large numbers of grubs in all stages of development and these numbers had been maintained despite climatic effects, stages of development and the effects of plowing. The chosen area represented the most heavily infested part of the field. It was disc-plowed and disc-harrowed once before the mud press-arsenic mix was applied February 14 to 28, 1934, at the rate of 44 tons of wet mud press per acre or 365 pounds of arsenic per acre. It was then disc-plowed twice, disc-harrowed once, deep-plowed once and disc-harrowed again in the order named. It was machine-planted in August, 1934, after being given a comparatively clean bill of health as to Anomala. The arsenic did not entirely eradicate the grubs but it definitely reduced the infestation, in comparison with the untreated portion of the field, to the point of control by parasites. The results of the excavations made between the time of application of the mixture and time of planting are shown below:

Small, Medium and Large Grubs—Total Per Acre

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date of Excavation	Plot 2 Mud Press Only	Plot 3 Mud Press-Arsenic	Per Cent Decrease
6/23/34	1,685,385	11,323	99.3
7/ 6/34	648,024	4,355	99.3
7/19/34	298,753	34,840	88.5
8/10/34	178,555	11,323	93.7

The high count of grubs shown under Plot 2 for June 23 consisted chiefly of very young grubs recently hatched before the excavation was made. The above data illustrate clearly that mud press is attractive to the Anomala beetle, an ideal medium for incubation and a perfect feeding ground for the young grubs.

Eighty-four per cent of the area of Field "C" received the mud press-arsenic treatment at the rate of 38 tons of mud press per acre or 314 pounds of arsenic per acre. Prior to this treatment the field was disc-plowed twice and disc-harrowed once. This mixture was applied April 16 to May 18 and from May 26 to June 2, 1934. The field was then disc-plowed once, disc-harrowed once, deep-plowed once and planted in August, 1934. The effectiveness of arsenic is indicated by the results of the excavation data shown below:

SMALL, MEDIUM AND LARGE GRUBS—TOTAL PER ACRE

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date of Excavation	Plot 3	Plot 4	Plot 5	
2/15/34	209,040	279,591	177,684	No
3/ 3/34	181,168	58,357	54,873	Treatment
3/19/34	162,877	94,068	111,488	Average of
4/10/34	106,262	185,523	148,941	3 Plots
5/ 2/34	229,944	54,873	181,168	
5/11/34	120,198	160,264	180,297	155,368

SMALL, MEDIUM AND LARGE GRUBS—TOTAL PER ACRE

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date of Excavation	Plot 3	Plot 4	Plot 5	
5/26-6/2 Application of Mud Press-Arsenic Mix				
6/19/34	70,551	47,034	86,229	Mud Press-Arsenic
7/ 2/34	21,775	62,712	44,421	Treatment
7/19/34	5,226	15,678	64,454	Average of
7/23/34	7,839	33,098	39,195	3 Plots
8/ 9/34	27,001	19,162	28,743	40,414

Results from periodic excavations indicate the trend of infestation under many field conditions and their respective treatments. We find a greater number of grubs in field areas treated with mud press alone than in those areas which have received no mud press and we find the least number of grubs in the field areas which have had the mud press-arsenic treatment. The above table shows an average of grubs equal to 155,368 for the three plots over a period of six excavations *prior* to the mud press-arsenic treatment. The average figure for the three plots over a period of five excavations *after* the mud press-arsenic treatment is 40,414 or a decrease of 74.0 per cent.

(3) *Plowed Into the Soil*—(c) *Mixed with Fertilizer:*

Another method of applying the fertilizer-arsenic mixture (See *Broadcast in the Cane Furrow*—c) to fields having light infestation of Anomala is by means of our subsoiler-fertilizer machine. It deposits the mixture to an average depth of 9 inches next to the root system where it is immediately effective. Subsequent irrigations disperse the mixture a little further into the soil mass and in closer contact with the grubs. This method of application saves the full labor cost necessary when applying the mixture by hand. No extra labor is needed on the subsoiler-fertilizing machine. We tried out this method in comparison with the surface application of the fertilizer-arsenic mixture. In both cases, the cane in the fields so treated seem not to be further damaged by Anomala. An explanation

is offered to the effect that when surface applications are made, the newly hatched and young grubs are killed by the arsenic near the surface; whereas, by the underground method, the young grubs on becoming more mature go deeper into the ground in their search for live cane roots, come in contact with the arsenic within the soil, which results in their death. This was just another method of arsenic application as a means of insurance against a heavier infestation.

(4) *Application of Mud Press-Arsenic Mixture to Ratoon Cane:*

The mud press-arsenic mixture from the mill is railroaded to the field and dumped near an irrigation ditch. It is fed into the irrigation ditches by men with shovels and, in this way, it is sluiced into the field by the irrigators. A blanket of finely divided mud press and arsenic is deposited in the furrows. The rate of application depends upon the area irrigated within a period of time, the amount of water used and the speed and number of men feeding the mix into the ditch.

Field "D" had a light infestation and was treated in the above manner. It is difficult to put on a uniform application, especially if there are only one or two dumping sites. We decided to put on a 200-pound application of arsenic per acre but it worked out that we had a larger amount near the dumping site and about a 50-pound application at a place in the field farthest removed from the dumping site. The more dumping sites there are, the better will be the control over the uniformity of application, but there are usually practical limitations to the number. The grubs that are already in the soil would not be affected by this treatment but it would reduce new infestation.

(5) *Application in Waterways:*

Waterways, such as level ditches, have bottoms of fine soft, loose soil which become attractive places in which the Anomala beetles lay their eggs. After a field has received an application of mud press sluiced in by water, there is, in addition, a layer of finely divided mud press which is deposited in the ditch and becomes even more attractive to the beetles. Thus we sometimes find the beginning of what promises to be a heavy infestation and in order to check this, we have applied arsenic in the ditches. It is then worked into the mud press and soil to a depth of several inches so as not to disturb the ditch too much. This method has proven to be effective as shown by examinations made from time to time on the checkup of grubs present in the ditches.

V. Plowing and Fallowing:

When a field becomes so badly infested with Anomala grubs that chemical measures become economically prohibitive, then the only solution is to plow and fallow until the grubs have disappeared or until the numbers are small enough to be kept under control by the natural parasites. Frequent plowing tends to keep the soil aerated and dry which aids greatly in keeping down infestation. This is particularly true during wet periods when Anomala grubs thrive in the soil. The grubs do not thrive so well in hot weather and go down deeper into the soil to avoid the dry, upper surface. As they go down deeper into the soil, there are less roots to feed on and they probably do not develop very fast. Heat and dry soil

are most detrimental to the newly hatched grubs which hatch near the surface of the soil. Anomala grubs travel deeper into the soil as they become more mature and are exceedingly active around stools of cane where they feed on live roots.

One or two disc-harrowings will spell death to most of the newly hatched and immature grubs while a disc-plowing will get many of the more mature grubs. Plowing exposes the grubs to the heat, birds and particularly the ants which attack them furiously. Ants are a very good agent in destroying grubs but they can operate only when the soil has been stirred up.

The knowledge of when to plow is greatly aided by the results of periodic excavations. It has been the practice here to establish numerous excavation areas scattered throughout the field in which excavations are made at bi-monthly and weekly intervals, depending upon conditions. There is a great variation in infestation over a field, which is clearly shown by the results in the table below. The effect on Anomala grubs of frequent plowing is also indicated by the same data. The data have been taken from excavations made in Field "D" which has received no treatment in the nature of molasses or mud press.

Small, Medium and Large Grubs—Total Per Acre

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Average
1/24/34	31,356	95,810	462,501	19,162	1,742	209,040	219,492	148,443
			Field was disc-plowed and disc-harrowed.					
2/28/34	30,485	85,358	385,369	1,742	0	16,549	63,583	83,298
3/15/34	35,711	45,292	155,038	0	1,742	31,356	90,584	51,389
			Field was disc-plowed a second time.					
4/ 4/34	21,775	116,714	21,775	2,613	0	28,743	53,131	34,964
			Field was disc-harrowed a second time.					
4/17/34	48,776	56,615	8,710	3,484	0	2,613	16,549	19,535

VI. Minor Control Methods:

The determination of the plantation to suppress the Anomala has been indicated by many kinds of control measures already described. An attempt has been made to leave nothing undone which gave reasonable promise of economical results. Anomala beetles and grubs have been destroyed by every practicable means. Mr. Pemberton, upon dissecting a number of beetles caught on flowers during flight found that a large proportion were females containing some unlaid eggs.

Anomala beetles enjoy feeding on the fuzzy flowers of paper bark trees, haole koa and the klu bush and can be easily caught. It is not worth while collecting the comparatively few from this source since these plants are not always in bloom and are found growing only in our waste lands. But, a plant of the genus

Ageratum having a small, fuzzy florescence grows about two feet tall, blooms all year and is especially attractive to the beetles. The plants are hardy and freely reseed themselves. These flowers were planted particularly in and around Anomala districts. The plants were set out along the ditches, roadways and edges of fields. Collectors received worthwhile remuneration for each bottle of beetles caught and, as they are easily caught while feeding on the flowers, large numbers were collected during flight periods.

During the first plowing operations when the grubs were most numerous, workers followed the plows to pick up Anomala grubs. An individual would average several thousand a day in heavily infested areas. They were paid by the number they picked up during the day.

Mynah birds did their duty toward the cause. They followed the plows around the field much like sea birds follow a ship at sea and probably consumed a great many grubs per day. They seemed to be fatter at the end of the day.

Flowering plants and certain kinds of weeds, the florescence of which is favored by the Scolia wasp for feeding purposes, are allowed to grow on roadsides, ditch banks, etc., throughout the fields of the plantation. Certain garden flowers have been planted along supply ditches and Mexican creeper along reservoir banks. An ample supply of favorite food promotes widespread population of the parasites.

VII. Parasitic and Insectivorous Agencies:

Scolia manilae has been the only parasite which has successfully controlled the Anomala, which it did until the last few years when Anomala got ahead of it on some parts of the plantation. It seems that there is a definite climatic effect on the relationship of Scolia development to Anomala development. This was particularly observed within the last year or so. The Anomala bred, developed and thrived during the cold, wet spell at the beginning of the year, while Scolia became scarce. For a period of six months Scolia was exceedingly rare.

A new parasite, called Elis and similar to Scolia in habits and structure, has been imported into the Territory from Guatemala by the entomologists of the Experiment Station. There are several species of which *Elis near pulchrina* is the largest importation. The first release of *Elis near pulchrina* was made on August 14, 1934, to one of our centrally elevated fields and further releases were made to a mauka and makai field where Anomala grubs are certain to be present in the soil.

A number of Tiphia parasites, also similar to Scolia, were released to one of our mauka fields in August, 1934.

Another beneficial insect has been imported by the Experiment Station. It is a large, predatory wireworm, of the genus Pyrophorus, which feeds upon grubs in the soil. The first shipment of these wireworms was received from Guatemala by the Experiment Station on June 4, 1934. The larvae will be developed to maturity in their laboratory, the adults will be mated and liberated to our fields.

The first release of the giant, tropical American toad, *Bufo marinus,* which was imported into the Territory from Puerto Rico in April, 1932, was made on August 18, 1933, to one of our reservoirs and to date we have liberated toads to all of

our reservoirs. The young ones eat ants and other small insects while the mature toads will eat almost any insect which will come to their vision. They are expected to do a great deal of good, not only with respect to Anomala control but also for other crops, vegetables and flowering plants. They are said to be nocturnal, generally hiding by day. They are beginning to spread through the cane fields and the larger ones are more in evidence.

Summary and Conclusion

Every effort has been made, in conjunction with the staff of the Experiment Station, to develop practical and economical measures for the control of Anomala, while awaiting the introduction of a parasite more effective than Scolia. A considerable degree of success has been attained.

The summary and conclusions are as follows:

1. Soil fumigants proved to be impractical and uneconomic.
2. Contact insecticides could not be properly dispersed in the soil mass and were not toxic to Anomala grubs.
3. Electricity was ineffective and commercially impractical. X-rays were experimented with merely to determine their effect on grubs.
4. Stomach poisons, particularly white arsenic, were the most successful of the chemical agencies. A technique for the application of white arsenic under various conditions was developed and the results have been satisfactory.
5. Plowing and fallowing are resorted to when natural control has failed, and chemical control becomes economically prohibitive.
6. Anomala beetles and grubs were collected and destroyed.
7. Parasites and insectivora can provide natural control. Scolia has failed at times when it was most needed. New parasites, similar to Scolia, have been imported into the Territory for Anomala control. A large, predatory, Guatemalan wireworm has been imported but not yet released. The giant American toad, *Bufo marinus,* is becoming established on the plantation. These new importations are expected to do a great deal toward keeping Anomala in check.
8. The Anomala grub is a difficult pest to eradicate, and there is much still to be learned about its life habits in the cane field under various conditions throughout the year.
9. The Anomala beetle is a prolific breeder. Its habits of flight are such that infestations are localized, and may occur at relatively widely separated points.
10. The life cycle of the Anomala is comparatively short and the grubs are ravenous eaters and do considerable damage in a short space of time.
11. The presence of Anomala grubs in the soil may not be known until indicated by the damage to cane growth, weak stools of cane and a peculiar yellow color of the leaves. Scattered patches of Anomala infestation can develop into large areas of such severe infestation as to necessitate plowing out a field.

Acknowledgment is hereby made of the cooperation of the plantation staff, and the staff of the Experiment Station in all of the work reported herein.

The writer is indebted to E. W. Greene for his helpful suggestions in the preparation of this paper.

Predisposing Factors in *Pythium* Root Rot

VII

By C. W. Carpenter

This paper, the seventh of a series on *Pythium* root rot and growth failure of sugar cane is a synthesis of observations made in Hawaii during the last four years. The related material in a considerable number of separate investigations, and cooperative endeavors with various members of the staff, is combined to show the present status of the research. The positive objective of crop improvement through an understanding of the causes of root failure and the practical aspects of the separate problems studied have determined the mode of procedure. The information gained from research now permits the assemblage of many fragmentary and seemingly contradictory details into a logical sequence to reveal the simple components of a problem utterly complex when considered in its entirety.

The environmental factors, which modify the susceptibility of the roots to the attacks of the fungus, *Pythium* sp.*, have been the chief concern. The experiments and observations are a further elaboration of the thesis (10, 13) that the susceptibility of cane roots not only varies with the varieties of cane but that within the variety susceptibility or resistance varies with the nutrition. The relation of excessive nitrogen fertilization, with respect to a particular variety, to increased susceptibility to *Pythium* root rot has been discussed in other papers of this series (10, 11, 12, 15). More recently, Cooke (20) and the writer have demonstrated that *Pythium* root rot is an important accessory in the growth failure of standard varieties over considerable areas of soil deficient in available phosphate. These soils are characterized by the Chemistry Department as "phosphate-fixing" soils. Observations indicate that with root susceptibility present, either the natural weakness peculiar to certain varieties or the susceptibility acquired by the naturally more resistant commercial varieties following malnutrition, the degree of rotting is vastly influenced by soil temperature and moisture. Various investigators (23, 25, 27, 28) have not failed to recognize the importance of soil temperature and moisture in *Pythium* root diseases.

It will be noticed that as the investigations of root rot and growth failure continue, *Pythium* root disease is demonstrated to be a larger factor in cane culture than was formerly realized. The literature of the past decade, reviewed herein to trace the progress of research, shows an increasing recognition of the relation of *Pythium* sp. to the etiology, not only of sugar cane root rot, but also of many obscure diseases of various crops. It is a matter of common knowledge in Hawaii that the Lahaina variety of cane failed over large areas and became gradually so undependable as a result of "root rot" that it was finally eliminated from our cultures. Coincidentally, the experience with Lahaina has been repeated on a smaller

**Pythium* sp. heretofore referred to as *Pythium aphanidermatum,* will be referred to henceforth as *Pythium graminicolum* (see p. 288).

scale with several other varieties which have been tried and largely discarded. *Pythium* root rot was more recently identified as a serious hazard in the early stages of cane seedling propagation. Various seedlings which have been selected and planted in spreading areas in the field also have failed each season from *Pythium* root rot. Certain seedlings have been observed to fail in one locality only while being very promising in others.

The marked improvement of cane growth in steamed or chemically fumigated soil has been a collateral subject of further investigation in relation to the general problem. H. P. Agee, Director of this Station, suggested that root-pruning parasites might be universally active in our commercial fields and that the growth improvement and the development of characteristically abundant masses of fine rootlets in steamed soil might be the result of the elimination of such root parasites. Potentially, this question was of basic importance and required thorough investigation. The investigations of the nature of plant response to sterilized or fumigated soils served later as a basis for cooperative experiments with Cooke (20) and the detection of the relation of *Pythium* root rot to growth failure in phosphate-fixing soils. The experiments reported herein indicate that the increased growth in sterilized soils is not, in general, due to the suppression of parasites but that it is largely a response to stimulative nutrients rendered available in larger amounts as a result of the treatment.

The subject matter of this paper which includes somewhat diverse phases of the general problem is conveniently presented under the following captions: "Review of Literature"; "Improvement of Cane Growth in Steamed or Fumigated Soils"; "Abnormal Nutrition as a Factor in *Pythium* Root Rot." The review of the literature, while by no means complete, is intended to include enough citations to sketch the trend of the investigation of root rot of cane and other grasses for the period under survey—1919 to date. Certain papers, not included in this review, are more appropriately cited in the section particularly concerned.

Review of Literature

Species of the genus *Pythium* have been reported during the past decade by various investigators in several countries not only as causes of root rot of cane, confirming the writer's (5) observations in 1919, but also of several other crops. Among the latter, the root rots and growth failures of the cereal crops, corn and wheat, are noteworthy as corresponding more closely with cane root rot.

In Puerto Rico, Matz (39) mentioned *Pythium* sp. and *Rhizoctonia* sp. as being isolated and considered as possible causes of cane root rot. His experiments apparently led him to consider the latter group of fungi more significant. Bourne (3), in the same country, presented evidence from his observations and stated that the *Pythium* associated with root rot in Puerto Rico was morphologically identical with that reported in Hawaii (foot note l.c. p. 63). As a result of earlier studies in Barbados, Bourne (2) reported *Rhizoctonia* sp. as active causes of root rot.

Lyon (35) reviewed the status of the root rot problem from 1895 to 1923, citing the important investigations. The reader is referred to this review and critical appraisal of the significance of the various theories and the evidence pre-

sented in their support. His citation of Hoffer and Carr's (30) investigations of corn root rot and the quotations therefrom regarding the relation of aluminum in acid soils and deficiencies of lime and phosphate to the disease, is particularly interesting in view of subsequent observations of a direct relationship of deficiencies of lime and phosphate to *Pythium* root rot of cane in Hawaii (20, 37). We quote the entire summary by Hoffer and Carr as of special significance at this stage in our progress of fitting together the complex interdependent factors in the *Pythium* root rot complex:

(1) One of the most characteristic differences between normally growing corn plants and those which become severely rootrotted is the condition of the vascular plate tissues in the nodes of the stalks. The plants which become severely rootrotted are those which have the nodal tissues discolored and in various stages of disintegration.

(2) This disintegration of the nodal plate tissues begins in the absence of any specific organisms in the tissues.

(3) The brown, yellowish brown, and brownish purple discolorations with their consequent disintegrations which are frequently found in diseased plants have been produced artificially by injecting solutions of certain salts of aluminum and iron into the plants. Definite chlorophyll and leaf-tissue changes have been produced also. Other factors, however, may operate to produce similar effects.

(4) These artificially induced changes in the plant parts closely resemble the phenomena which develop in plants growing in the field under conditions favorable to rootrots.

(5) The most severe cases of rootrots have been found in soils notable because of their deficiencies of lime and available phosphates.

(6) Such soils have variable quantities of salts of aluminum and iron available for absorption by plants.

(7) Corn plants show marked differences in the quantities of aluminum and iron salts which are absorbed by them. These differences develop when the salts are available in subtoxic concentrations in the soil and are believed to be due to specific selective capacities of different plants to absorb the available aluminum and iron salts from the soil. This type of selective absorption cannot operate when the aluminum and iron salts occur in quantities which are toxic to the roots.

(8) A definite cumulative toxicity of aluminum salts within the plants was established by the injection experiments, and it is believed that the same phenomenon occurs naturally in the field. The relative quantities of the available metals and of nitrates in the soil determine, in a large measure, the rate of development of the cumulative toxicity of the metals within the plants. Those plants which contain the largest quantities of these metals are the ones which seem to develop the most severe cases of rootrots when the organisms are present in the soil and the meteorological conditions favor their optimum growth.

(9) When abundant aluminum injuries occur in the corn plants in certain fields it is an indication that the soil is deficient in available phosphates.

(10) The application of lime and phosphates to soils in which rootrots have developed in destructive proportions has been decidedly beneficial in controlling them. The use of limestone alone in some instances proved harmful, but in all cases studied so far the application of available phosphates produced plants which were better and more resistant to the rootrots.

McGeorge (40, p. 322) pointed out that the more resistant varieties of cane had shown evidence of root rot in our upland soils, which differ from lowland soils in being more acid, a feature accompanied by phosphate, and occasional potash, deficiencies. He mentioned that a number of investigators in soil fertility studies including those in Indiana, Massachusetts, New Jersey, Rhode Island and the Bureau of Plant Industry, U. S. Department of Agriculture, had reported salts of iron, aluminum and manganese associated with the low root vitality of

crops grown in acid soils. McGeorge stated that he had found the same abnormal characteristics in stalks of cane that Hoffer reported in corn and that the toxicity of aluminum salts had been demonstrated. He (41, p. 468) also reviewed Hoffer's studies accompanying the citations therefrom with references to observations in Hawaii.

Stewart (50) discussed growth failure of H 109 in mauka (upland) fields on the island of Oahu, which was corrected by additional fertilization and extra irrigation. The following paragraphs are quoted from his report:

Further interest, in the composition of the Oahu soils, was aroused during the past year by the behavior of H 109 cane in Field 20. A number of poor spots appeared in portions of this field where the cane seemed to be affected by root rot. Soil samples were collected from these poor spots and from adjoining land where good cane was growing. The majority of the samples from both the good and poor areas were low in available phosphates and contained a minimum quantity of available potash. The total potash supply was excellent, but the total phosphates were distinctly low for Island soils.

A definite connection has been shown recently in the Eastern United States, between deficiencies of available phosphates and potash and the occurrence of root rot in corn crops. This trouble has been found, usually, on very acid soils where toxic salts of soluble aluminum and iron are present. Such soils are found in these Islands in the mauka lands of the unirrigated plantations. At the same time, there is considerable indication that plant food deficiencies may contribute to root troubles in soils that are not notably acid. It seemed desirable, therefore, to make a more general survey of the Oahu Sugar Company lands.

The results of this work showed that most of the areas which were low in available plant food were located in the mauka fields, but that Field 20 was largely low in phosphate content. Further field experiments with phosphates and potash were recommended. It was concluded that the appearance of root rot in Field 20 was due to a deficiency of plant food and a poor water-holding capacity in the soil of limited areas. The affected cane was given additional fertilization and extra irrigation and has now recovered completely.

Naquin (42) has suggested the relation of a deficiency of potash to a form of root rot at Honokaa Sugar Company, the symptoms being similar to those of Lahaina failure. He reported his observations, in part, as follows:

Recently a case of acute potash deficiency occurred in a kuleana where cane was planted for the first time four years ago. This was D 1135, and the symptoms were noticed about 6 months after the cane had been cut, and when the young cane was growing vigorously and there was an excessive amount of cane per linear foot. Gradually the symptoms developed and spread, so that the whole area was affected in different degrees of acuteness.

Field tests were started 3 months ago, when applications were made of nitrate, 200 lbs. active ingredients per acre, potash 400 lbs. and phosphate 400 lbs. per acre.

The cane where potash was applied immediately picked up and started a new growth, and cane which had reached the size of a lead pencil and had only a few leaves immediately increased the number of leaves and gained in girth. Three months after the application of potash all of the plants were growing normally.

In cases where nitrate and phosphate were applied the conditions were more or less aggravated, and most of the cane died out and a secondary crop of suckers is coming out at present.

This condition, as well as other similar conditions, which have occurred in small patches here and there on the plantation have been studied and diagnosed by different investigators as root rot. McGeorge, in Bulletin 49, of the H.S.P.A., cited one of the areas as being deficient in potash, and found in pot cultures that the root of the cane was stimulated by potash application. From this it must not be assumed, however, that all soils which respond to potash show symptoms of root rot. It is only the acute stage of potash deficiency that produces this condition.

Valleau, Karraker and Johnson (54) pointed out in 1926 that the confusion in the literature of corn root rot diseases was largely due to the fact that investigators continued to emphasize a relationship between poor seed and seedling blight. Attention had been devoted to seed-borne pathogens neglecting the organisms actually associated with the diseased corn roots. They believed that plant pathologists had not given sufficient attention to an attempt to separate the various diseases concerned. The fact was emphasized that there was a root disease of corn distinct from seedling blight and the depressed growth resulting therefrom, and that the organisms previously considered as etiologic factors in corn root rot were not concerned. They pointed out (p. 455) that the cause of corn root rot was still given as *Gibberella saubinetti* in the *Plant Disease Reporter* in 1925 (53). These investigators, pioneering along such lines, concluded as the result of experiments that corn root rot, other than seedling blight known to be caused by seed-borne organisms, is a soil-borne disease caused by a fungus similar to the one causing cane root rot in Hawaii. The type of injury produced was stated to be (l.c. p. 475) remarkably similar to the injury to Lahaina cane pictured by Carpenter (5).

Branstetter (4), as a result of extensive field and laboratory studies in Missouri, arrived at the same conclusion as Valleau and his associates, i.e., that corn root rot is a soil-borne disease similar to cane root rot in Hawaii.

Johann, Holbert and Dickson (32), in 1926, reported an undetermined species of *Pythium* as the cause of seedling blight of corn in Illinois and Wisconsin. In a later publication (33), they summarized their observations in part as follows:

> *Pythium* injury to corn may be manifested as (1) a rot of the embryo, preventing germination, (2) as a seedling blight after emergence; or (3) as a root rot that tends to reduce the size, vigor and yield of the maturing plant. The causal organism has just been described by Drechsler (22) as *Pythium arrhenomanes* n. sp. . . .
>
> Experiments in which open pollinated and inbred corn was inoculated with *Pythium arrhenomanes*, at the time of planting, in soil temperature control tanks indicate that soil temperatures near 16° C. or lower, together with high soil moistures, are so favorable for infection that germination of corn kernels may be prevented or seedling blight produced. When inoculated corn is not killed in the seedling stage, the height and the dry weight of tops of the plants are reduced. The highest percentage reduction occurred at the lower temperatures. Evidences of differing degrees of resistance or susceptibility were manifest in different inbred strains of corn.

In the meantime, in 1927, Edgerton and Tims (24 p. 32) reported that a species of *Pythium* was consistently found in cane roots in different parts of the sugar cane belt. They remarked that *Pythium* was the only fungus found in Louisiana which consistently entered the stele portion of the root. Also, they remarked that the whole root was rotted, agreeing with our local observations.

Edgerton and associates (25, 27, 28) presented experimental data on the relation of soil moisture and temperature to the severity of cane root rot in Louisiana. They pointed out that root rot of sugar cane is more severe in poorly drained fields and in seasons of excessive rainfall and exceptionally low temperatures in January, February and March. Flor (27, p. 327), who used corn as an indicator in his experiments, reported some of his observations as follows:

> Although the growth rate of *Pythium* increases with the temperature up to 30° C., the effect of the fungus on growing plants is more severe at lower temperatures. Only young

terminal portions of the roots are subject to attack and it is possible that the cool weather holds the roots in a susceptible condition longer than warm weather.

The results obtained in the soil-moisture studies agree closely with conditions in the field. The effect of the fungus was severe only in soils with a water content greater than 50 per cent of the moisture-holding capacity. This emphasizes the importance of the best drainage possible, especially during winter and spring, when the cane grows very slowly. . . .

Pythium injury to germination and growth of corn decreased with rise in temperature. At 35° C., *Pythium* did not injure corn. At 30° C., there was an appreciable amount of injury, and, as the temperature was lowered, injury became more severe. *Pythium* injury to germination and growth of corn increased with the water content of the soil but was less severe in wet soils in warm than in cold weather.

Edgerton, Tims, and Mills (25) reported that certain species of *Pythium* which attack cane also attack a number of other members of the grass family including corn, sorghum, wheat and oats.

Rands (43) recognized the importance of *Pythium* sp. in root rot of cane in the southern United States. The most aggressive *Pythium* was considered to be representative of a type which was potentially the most important single factor in the cane root disease problem. This is the type of *P. arrhenomanes,* the cause of maize root rot in Wisconsin. The *arrhenomanes* group was thougth to include the Hawaiian *Pythium,* (see p. 287) cultures of which were included in his survey. As above mentioned, *P. arrhenomanes* was described by Drechsler in 1928 as a new species causing maize root rot.

Pythium Root Rot of Seedlings. The following excerpts are quoted from the writer's reports (17, 18) for the years 1931 and 1932.

In the (cane) seedling work steam sterilization of soil and flats insures the young plants a healthy start. Sterilized soil, however, furnishes an ideal environment for *Pythium* root disease and increases the susceptibility of plants grown therein in the same way as excessive applications of nitrogen. The apparently ubiquitous water and soil fungus, *Pythium,* soon infects the roots with disastrous results. The use of natural soil free of weed seeds or freed of such seeds by previously allowing them to germinate, seems to offer promise for use in seedling propagation. The elimination of weed seeds by germination before the soil is used for seedlings is mentioned in a recent paper by U. K. Das, referring to a practice in India. Rich soil and excessive moisture are the important factors in favoring *Pythium* root disease. Temperatures unfavorable for cane growth do not restrict the fungus but promote *Pythium* root collapse, at the same time retarding root replacement.

This disease had assumed considerable importance in seedling propagation during the expanded program of seedling production in the years 1928-29 and 1929-30. During the 1930-31 season the loss of seedlings was severe. Further sanitary measures were put into practice, this department cooperating with the geneticists in an attempt to eliminate the *Pythium* hazard. In the 1931-32 season this disease caused scarcely any loss of seedlings. It now appears that the disease can be completely controlled by a sanitation program, constant vigilance at all stages in the propagating house being essential to prevent seedling infection. When both the soil and the seedling flats are sterilized and care is observed to prevent infection from outside sources, no further difficulty is experienced. No treatment has proved successful in saving the seedlings once a flat has become infected.

In the last two seasons this disease has been under satisfactory control. Where excess moisture has been present, either applied in excess in the greenhouse or from rainfall where flats of young seedlings have been in the open at low temperature, root rot has been serious. Rich soil, excessive moisture and tempera-

tures low enough to check normal cane growth are favorable factors for excessive root destruction by *Pythium*.

Vanterpool and Ledingham (55), in a paper on the browning root rot of cereals, issued in 1930, considered that the disease under investigation was a *Pythium* root rot problem of cereals, especially of wheat, similar to the root rot complex of cane in Hawaii, Louisiana and elsewhere. Vanterpool and Truscott (56) reported in 1932 that under field conditions *Pythium* rarely reduced germination or injured the wheat seedlings but that it consistently caused a root rot which reduced the size and vigor of the growing plants. Two new forms of *Pythium* were concerned, *Pythium arrhenomanes* var. *canadensis* and *P. volutum*. The latter is reported (l.c. p. 78) as causing root rot of *Triticum aestivum* L., (wheat) and *Avena sativa* L., (oats) in Saskatchewan; also as an aggressive root parasite of *Hordeum sativum* L., (barley) *Secale cereale* L., (rye) and *Zea mays* L., (corn) when artificially inoculated. *Pythium arrhenomanes* var. *canadensis* causes root rot of *Triticum aestivum* L., in Saskatchewan. This variety is also an aggressive root parasite of *Avena sativa* L., *Hordeum sativum* L., *Secale cereale* L., and *Zea mays* L. Both fungi were considered to be closely related to the cane *Pythium* of Hawaii, but different therefrom. We quote from Vanterpool and Truscott as follows:

> Penetration of the roots of the cereal host by the two species of *Pythium* just described occurs readily through both the epidermal and root hair cells. Where the infection hypha comes in contact with the host cell wall, a small appressorium develops and a narrow infection tube pierces the cell wall, and, once inside, regains the normal diameter of the mycelium. The same phenomenon usually occurs when hyphae pass from cell to cell within the host. In so far as can be observed, the host offers no resistance to the invading parasite. The growing point of root or rootlet is most commonly attacked and consequently further growth in length is either retarded or stopped completely. Both fungi grow rapidly through the cortex in all directions and in the course of 24 hours or less have entered the stele of young roots....

In cooperative studies with the writer (14, p. 104), D. M. Weller found that *Pythium* was able to penetrate a cane root near the tip, apparently by pressure, and reach the center in 4 hours.

Flor (28, p. 32) studied the penetration of corn roots by *Pythium* and reported that infection near the root tip was unusually rapid. He stated that within 2 hours, the *Pythium* hyphae had entered the epidermal cells; in 4 hours, the first three or four tiers of cells had been penetrated; and in 6 hours, the fungus had nearly reached the central cylinder. Within 24 hours, the root tip had been completely invaded by the fungus, and the cells had collapsed. Penetration of cortex tissues that were 16 hours old when inoculated was nearly as rapid as through the root tip cells. The uninjured cortex of roots 48 hours old, when inoculated, was not as readily entered. Flor concluded that most of the infection and rotting occurs in young tissues, which is in harmony with our observations.

A new and serious disease of maize, said to be different from root rot caused by *Pythium arrhenomanes* in the United States is reported by Curzi (21) in Italy. The cause was considered to be a *Pythium* sp. of the *P. gracile* group. This disease was said to have caused a loss of 80 per cent of the crop.

The occurrence of *Pythium* root rot of maize and cane in the Philippine Is-

lands is recorded by Roldan (45). Concerning root rot of rice in the Netherlands East Indies, Leefmans (34) reported as follows:

> Root rot of rice, though still widespread, appears to have generally declined in severity, partly as a result of the application to the soil of double superphosphate. Infection by *Pythium* was again observed on rice crops cultivated under dry conditions at Bodjonegoro (Rembang).

Sideris and Paxton (49) supported the writer's (5, 6) opinion that pythiaceous fungi were responsible for considerable root damage of pineapples and were, in part at least, responsible for pineapple "wilt" disease. This disease in its several forms is common in the pineapple fields of Hawaii. The foliage of the plants turns to various shades of yellow, red or brown, shrivels slowly and the plants often die. Scant root systems are the rule on such plants. Sideris and Paxton state (l.c. p. 496) that, "root rot caused by pythiaceous organisms is probably one of the important causes for the development of the disease known as wilt."

Sideris (48) made a taxonomic study of the pythiaceous fungi associated with pineapple root rot. It may be noted that a subdivision of the family *Pythiaceae* into the genera *Nematosporangium* and *Pythium* has been adopted by some authorities, while others have not recognized *Nematosporangium* as a genus and have supported a division of the family into the two genera, *Pythium* and *Phytophthora*. Sideris advocates the recognition of *Nematosporangium*. He described eight new species and one new variety of this genus.

Vanterpool and Truscott (56, p. 71) reported difficulty in identifying their *Pythium* types with those of several closely related forms described by Sideris, by the descriptions alone. Their comment on these species and the difficulties involved in taxonomic studies of the *Pythiaceae* is quoted as follows:

> The identification of many of these species which are morphologically very similar is unfortunately based on cultural differences on a variety of plant media some of which (and among them the most important, papaya agar) are unobtainable in temperate climates. Some justification may be found for this procedure, but it unquestionably makes it more and more difficult for workers who have obtained one or more of these morphologically similar species to know definitely what forms they are working with. The accurate determination of the identity of a species would entail an enormous amount of comparative culture work and would have to be undertaken by one or two authorities on the group. The most common Saskatchewan wheat *Pythium* is morphologically very similar to several species described by Sideris but whether it is identical with any one of them cannot definitely be determined from the descriptions alone.

We have not made a critical study of the family *Pythiaceae* and do not propose to enter the discussion as to what constitutes a species. It is obvious that to distinguish between such closely related forms a meticulous technique is necessary. Whenever it is sufficiently important to accurately identify a certain form to justify the work required, it is desirable that the technique be workable by all investigators who may find it expedient to employ it.

In the first description of the *Pythium* sp. associated with root rot in Hawaii (5, 7), it seemed to the writer that in the current state of knowledge, it was far better to state that this fungus with its prosporangia of the *Nematosporangium* type was morphologically like certain described forms than to claim new species on the basis of small differences. Several investigators have expressed opinions

as to the identity of the cane fungus which we have been referring to as *Pythium aphanidermatum* (Edson) Fitz. In Bulletin III, part 1, Botanical Series, H.S.P.A., the fungus was stated to be morphologically identical with *P. Butleri* Subramaniam and *Rheosporangium aphanidermatus* Edson. The name *Pythium Butleri* Subramaniam was given preference by the writer. Fitzpatrick (26) presented reasons why this fungus should be more appropriately referred to as either *Pythium* or *Nematosporangium aphanidermatum* (Edson). Drechsler (22) stated that the cane *Pythium* as described and figured by Carpenter had a slightly different type of antheridium than *P. aphanidermatum* and, one which more resembled that of his new species *(P. arrhenomanes).*

Rands (43) compared cultures of the Hawaiian *Pythium* sp. from root rot of cane with the isolations he was studying. He stated that the most parasitic group had been tentatively assigned by Drechsler to *P. arrhenomanes,* the causal fungus of maize root rot in Wisconsin. These fungi were considered potentially the most important single factor in the root disease problem of cane. The cane *Pythium* from Hawaii was considered closely related to this group.

Matthews (38) agreed with Fitzpatrick and Carpenter that *Pythium Butleri* is the same as *P. aphanidermatum.* The opinion was expressed that the Hawaiian *Pythium* is not *P. aphanidermatum* and it was classified as identical with *P. graminicolum,* described by Subramaniam (51) in 1928. The latter isolated a species of *Pythium* from root rot of wheat. We quote a portion of his description as follows:

> It does not agree with any of the described species of the sub-genus *Aphragmium.* It agrees with the description and drawings of the *Pythium* on sugar cane studied by Carpenter (7) in Hawaii.
>
> . . . The measurements of the *Pythium* (oogonia and oospores) on cane are slightly bigger than those of the *Pythium* on wheat but they are not sufficiently great, I think, to separate the two fungi.
>
> A new name is proposed for the fungus on wheat, "*Pythium graminicolum* n. sp."

We are forced to admit that in this case it would have been less confusing to create a new species for the Hawaiian cane *Pythium* in the first place, however small the difference from described species.

A paper by Rands and Dopp (44) entitled, "Variability in *Pythium arrhenomanes* in relation to root rot of sugarcane and corn" was received (September 5, 1934) after the manuscript of this paper had been submitted for publication. In order to clarify the synonymy of the *Pythium* sp. with which we have been chiefly concerned, we quote from Rands and Dopp as follows:

> This paper presents the results of laboratory and greenhouse studies on strain variability of the principal sugarcane root-rot fungus, *Pythium arrhenomanes* Drechsler, in Louisiana and Florida. Additional cultures from corn root rot in the North Central States, the cereal root-browning fungus from Canada, and sugarcane strains from Hawaii and Mauritius were included in the laboratory comparisons.
>
> Despite wide differences in size of oogonia, number of antheridia, rate of growth in artificial culture, and response to temperature, and despite variation in hydrogen ion concentration and in virulence among the local forms on sugarcane and corn, certain constant and distinctive characteristics of the sexual organs unquestionably classify all the 70 isolates tested as *Pythium arrhenomanes.* Nine of the recently described *Nematosporangium* species of Sideris mainly from pineapple in Hawaii, are also included under the species.

Rands and Dopp (p. 218) are quoted again as follows:

> That all the isolates herein studied belong to this species is obvious from their morphologic similarity alone. The typical crook-necked antheridia and the remote connection between male and female organs are believed to be more characteristic of the species as a whole than a large number of antheridia, emphasized by Drechsler. Unfortunately, all the relatively few fruiting cultures studied by Drechsler showed large numbers of antheridia but such are not characteristic of many representatives of the species. A considerable proportion of the isolates included in these studies had typically but 4 to 10 visible antheridia instead of the 15 to 20 mentioned in the species description. . . .

Henceforth, as a result of the comparative studies of cane and corn root-rot fungi reported by Rands and Dopp, the parasitic fungus associated with growth failure of cane in Hawaii referred to first as *Pythium Butleri* Subramaniam and more recently as *P. aphanidermatum* (Edson) Fitzpatrick, will be considered synonymous with *P. arrhenomanes* Drechsler. According to Subramaniam (51) cited above, his *Pythium graminicolum* is identical with the *Pythium* in Hawaii, a decision in which Matthews (38, pp. 51-59) concurs. The species description of *P. graminicolum* apparently takes precedence over that of *P. arrhenomanes* by Drechsler since Subramaniam's paper published the same year as Drechsler's—in what month we do not know—bears the note "Received for publication the 21st February, 1928." A footnote states that the paper was read at the fifteenth meeting of the Indian Science Congress, Calcutta, 1928. This meeting was held January 2 to 7, 1928. The Proceedings of this Congress, published in 1928 without record of the month, contains an abstract of Subramaniam's paper (page 232) which states that the name *P. graminicolum* is proposed for the *Pythium* found on wheat and sugar cane. Drechsler's description of *P. arrhenomanes* was published in the October number of *Phytopathology*, 1928. References made to the Hawaii cane *Pythium* throughout this paper as *P. graminicolum*, before receiving the paper of Rands and Dopp, have therefore been left unrevised, in view of the apparent priority of that name.

The foregoing review of the literature illustrates the increasing attention given by phytopathologists in various parts of the world to pythiaceous fungi as active causes of obscure plant diseases of the "root rot" and "growth failure" types. The citations furnish considerable correlative information in support of experimental evidence presented later to reveal the determining relation of various forms of abnormal nutrition of the host plant to susceptibility.

Improvement of Cane Growth in Steamed or Fumigated Soils

The improved growth of plants in steamed soil in comparison with non-steamed soil has long been a subject of comment in agricultural literature. A similar improved growth accompanied by similar changes in root habit also occurs in chemically fumigated soil. Studies of this phenomenon, collaterally of interest in the general root rot problem, have received attention in cooperation with the Chemistry, Entomology and Agricultural Departments. The reader is referred to Webster's (59) paper for a resumé of the literature on plant response to sterilized soils. It may be said that some soils are reported to show a growth response when partially sterilized but growth depression when completely sterilized. In our experience with cane, Hawaiian soils, with some exceptions, respond to complete

sterilization, by which we mean steaming in bags 3 hours or more at 25 pounds pressure.

Maxwell O. Johnson of the California Packing Company had called attention to the remarkable improvement in growth of pineapples on Hawaiian soils treated with chloropicrin. Subsequent pot studies by William Hartung and C. L. Crutchfield of the Pacific Guano and Fertilizer Company, showed similar growth improvement of tomato plants following chloropicrin treatment of soil where pineapples had failed. Cooke (20) observed a similar response of growth failure soils with Sudan grass as an indicator plant. These observations, as Cooke has outlined in more detail, inspired the effort to learn how the improvement of crop growth was effected. Cooke stated (p. 171) that a respiration test showed that more carbon dioxide was given off by untreated soil than by chloropicrin-treated soil. Coincidentally, as a matter of interest, it may be pointed out that just such an observation by Russell and Buddin (46) regarding oxygen absorption by soils inspired their classic investigation of the interesting phenomenon of improved growth of plants in partially sterilized soil. A short review of their fundamental work on the subject is necessary as an introduction to this phase of our studies.

Russell and Buddin stated that much of the work recorded in their paper entitled, "The Action of Antiseptics in Increasing the Growth of Crops in Soil" was the outcome of a mistake committed by a youthful laboratory attendant. The absorption of oxygen by various chemical substances was under investigation. Soils were finally included and it was observed that fertile soils absorbed oxygen more rapidly than non-fertile soils of the same character. The rate of oxygen absorption was useful as an indication of productiveness. Since the oxygen absorption was reduced in sterilized soil, it was concluded that the process was largely due to microorganisms. Through an annoying mistake sterilization was only carried out at 100° C. and not at 130° C. The partially sterilized soil was used in an experiment with remarkable results. This soil absorbed oxygen much more rapidly than the unsteamed soil. Subsequently, partial sterilization with volatile antiseptics gave similar results. Pot experiments showed, as anticipated, that the partially sterilized soils were more productive than untreated soils. This fact had already been noticed by a vine grower in Alsace, who treated his vineyard soil with carbon disulphide to control phylloxera, and noticed a marked increase in crop. This last observation inspired an investigation by Hiltner and Störmer (29) in Germany, who associated bacteria with the beneficial effects of sterilization.

Hutchinson, according to Russell and Buddin (46, p. 1137), definitely established the following propositions:

1. Partial sterilisation causes first a fall and then a large rise in the numbers of bacteria in the soil.

2. Simultaneously there is a considerable increase in the rate of production of ammonia from the complex nitrogenous compounds of the soil.

3. The increased productiveness of partially sterilised soil is due, at any rate in part, to this increased productiveness of ammonia.

4. The increase in bacterial numbers is the result of improvement in the soil as a medium for bacterial growth and not an improvement in the bacterial flora. Indeed, when the original bacterial flora is introduced into partially sterilised soil the numbers rise even higher than when the new flora is left to itself.

5. The improvement in the soil is permanent.

6. But if some of the untreated soil is introduced into partially sterilised soil, the bacterial numbers after an initial rise begin to fall and the fall is out of all proportion to the amount of added soil.

These and other experiments show that ordinary soil contains a factor which keeps down the bacterial population and prevents it from attaining maximum numbers. The factor is not bacterial; it appears, however, to be living, and to consist in organisms larger than bacteria, more readily killed, and more slow in multiplication under soil conditions. Search for organisms fulfilling this description was made, and revealed the presence of numerous protozoa, the existence of which had hardly been suspected before.

When this detrimental factor is put out of action by gentle heat or by antiseptics, the bacterial numbers increase, more plant food is formed, and the productiveness of the soil is raised.

Webster (59) reported observations in two pot experiments. One experiment was with nine varieties of cane in steam-sterilized soil, formaldehyde-treated soil, and untreated soil. In every case the plants in the sterilized and treated soil responded with superior top and root growth. A sample root system representative of each variety in each treatment was examined by R. H. Van Zwaluwenburg and the writer. Their observations are quoted from Webster's paper (p. 340) as follows:

Herewith is submitted a report on an examination of the roots of 27 samples of cane from an experiment conducted by J. N. P. Webster. These 27 samples consisted of 9 varieties in three series as follows:

A—Check Makiki soil
B—Steam-sterilized Makiki soil
C—Formaldehyde-treated Makiki soil

The varieties of cane were as follows:

D 1135	Lahaina
P.O.J. 2878	Badila
Yellow Caledonia	Natal Uba
P.O.J. 36	Striped Tip
H 109	

The top growth of the canes in the treated soils was in general so superior to that of the plants in the natural Makiki soil that it seemed worth while to know whether or not the observed improvement was due to repression of parasitic organisms, and with that in mind the roots were examined.

The root systems of all plants were carefully washed. The following general observations were made:

1. The root growth of the plants in the steam-sterilized soil was in most cases superior to, and in all cases at least equal to, that obtained in formaldehyde-treated soil.

2. The root systems in the treated soils were in all cases far superior to those in the natural soil. By superior is meant of greater bulk and with a very conspicuous increase of fine rootlets, particularly in the upper 6 inches of soil. (A single exception was the Natal Uba in soil treated with formaldehyde; here depression resulted.)

3. The roots in the treated soils were conspicuously lighter in color than those in the checks.

4. The roots of all three series showed conspicuous injury due to contact with the container.

5. *Heterodera radicicola* and *Tylenchus similis* were identified in all pots of the check series. In every case, however, damage by these nematodes was so slight that it was impossible for us to believe that the marked reduction in root and top growth shown throughout

the check series was due to these factors. No evidence of rootlets having been destroyed by nematodes was seen in the check series. In only two cases of treated pots, one steam sterilized, the other formaldehyde treated, were traces of Heterodera found. No Tylenchus was found in roots of treated pots.

6. No evidence of *Pythium* root rot was observed in the series in treated soils. In the natural soil an occasional softened root was found, but in no case was the fungus *Pythium* definitely observed. Such roots as were softened appeared to have succumbed as a result of stagnation in the water in depressions at the bottom of the pots.

The striking difference between the roots of treated and check pots was the comparative lack of fine rootlets in the latter. There was no evidence that this lack of fine roots was due to the destruction by parasitic organisms of rootlets already formed. On the contrary such rootlets apparently had never been developed in corresponding abundance in the check plants.

It is our presumption, therefore, that the essential factors controlling the abundant production of secondary rootlets are physical and nutritional in nature. When ample nutrients in an improved physical environment were available, a close mat of fine roots developed.

We suggest that if this project is to be followed, a series of soils be included wherein a superabundance of nutrients is present in both sterilized and unsterilized units, to eliminate the possible lack of nutrient factors. Fine screened soil might be used to make the physical condition of steamed and check soil more nearly comparable. Inoculation of a series of steamed soils by the introduction of small amounts of natural soil might throw additional light on the biological-nutritional phases of the problem.

The statement is made by Russell (l.c. p. 1141) that only soils low in nitrogen respond to sterilization and that the same effect secured by sterilization could be had economically by applications of fertilizer. It should be noted that the soil used by Webster was from Makiki field plots. This soil, naturally low in nitrogen, is one in which *Pythium* root rot has never been considered a crop hazard, even for Lahaina cane. Elimination of *Pythium* by the treatments apparently was not an important factor in the improved growth.

Webster's first experiment led to a second one with the idea of duplicating the response to steam sterilization by fertilizing with phosphate, with complete fertilizing mixture, and with chloropicrin treatment. The experiment with the variety D 1135 comprised sterilized and unsterilized Makiki soil with the treatments indicated in Table I, quoted with comment from Webster (Table II, l.c. p. 348). The table also shows the dry weights of the tops and roots.

TABLE I

Treatments	Sterilized Soil		Unsterilized Soil	
	Tops	Roots	Tops	Roots
Check	360.1	140.2	115.6	69.9
Unsterilized soil added (2 lbs.)	385.6	134.2	...	...
1000 lbs. P_2O_5	326.3	130.5	89.6	60.8
1500 lbs. P_2O_5	291.2	132.9	95.8	58.1
100 lbs. N, 500 lbs. P_2O_5, 500 lbs. K_2O	419.6	111.5	160.5	89.8
Pythium	405.1	111.0	86.4	49.1
Chloropicrin 75 lbs. per acre	380.1	145.0	229.6	102.3

A first glance at the above table shows the remarkable gain of the top and root weight of the sterilized soil series over the unsterilized series.

The greater weight of tops and roots of the sterilized soils is in accord with that found in Experiment 1.

The response to chloropicrin in the unsterilized soil is considerable and is probably due to its sterilizing effect upon the soil.

The following comments, based on Webster's data, may be entertained:

1. *Nitrogen:* The results with complete fertilizer tend to support Russell's statement that the response to sterilization may be realized by fertilization. The failure of the plants, grown without shelter from rains, to respond in the same degree might be interpreted as due to leaching of the nitrogen from the fertilized pots. Nitrogen at the rate of 100 pounds per acre mixed with the soil before planting might not be equivalent in growth value to ammonia liberated gradually in the unfertilized soil by accelerated biological processes following sterilization. The plants in soil fertilized with the complete mixture and sterilized were superior in top growth and inferior in root growth to the plants in sterilized unfertilized soil.

A considerable growth response to chloropicrin in unsteamed soil was evident. This response indicates that heat and the immediate and direct changes such as might result from steam sterilization are not the vital factors. No significant response was secured by chloropicrin treatment of steamed soil, indicating not only that chloropicrin did nothing that steaming had not already done, but also that chloropicrin in itself added no nutrients directly or indirectly by chemical action.

2. *Phosphate:* It appears fair to assume that phosphate applications and the *Pythium* inoculations, in this soil with D 1135, were without appreciable effects. The lack of response to phosphates indicates that the soil was sufficiently supplied with this element to balance the nitrogen and potash present. Both sterilized and unsterilized soil benefited from the nitrogen and/or potash in the complete fertilizer.

3. *Addition of Unsterilized Soil to Sterilized Soil:* The addition of two pounds of unsterilized soil to the sterilized units was without apparent harmful effect, indicating that root parasitic flora or fauna were not factors the suppression of which by sterilization permitted "normal" growth.

Various collaborators in this project have commented upon the superior root systems of sugar cane grown in steamed or chemically fumigated soil. The roots are white, as in water cultures, and in the upper soil layer form a dense mat of fine, fibrous rootlets. Healthy roots in similar soil, unsterilized, are rarely, if ever, as light in color and have not been observed to be accompanied by such a mass of fine rootlets. Russell and Petherbridge (47) mention just such a remarkable development of fibrous roots by plants grown in soils heated to 100° C., unlike anything obtained in untreated soils.

It was of interest to Mr. Agee and our co-workers to learn if such extensive root systems could be regarded as normal, and if the root systems of crop cane in general were curtailed by unknown root-destroying parasites. As noted above, in the comment of Van Zwaluwenburg and the writer on Webster's experiment, examination failed to produce any evidence that parasites—either microfauna or microflora—were significantly concerned. However, the possibility that such factors are active was not overlooked as a result of this lack of evidence. In the light of our observations, it appeared more probable that the growth response to sterilization was due to a greater availability of nutrients, presumed to result from changes in the soil biology, a predominating viewpoint in the literature.

It is obvious that there are two phases to the question of enhanced growth in sterilized soils, as follows: (1) The elimination of parasites such as *Pythium* sp. in soils where root parasites are significant factors. (2) The stimulated growth in soil where the suppression of root parasites apparently is in no way concerned. The experiments recorded below, in which *Pythium* is not considered to have been a factor, tend to support the view that the stimulated growth following sterilization by steam or chemical fumigation is due to enhanced nutrition, presumably from ammonia released by biologic activity.

Mixed Sterilized and Unsterilized Soil: It was thought that the growth of cane in a series of steamed soils mixed with gradually increasing increments of unsteamed soil might serve as a key experiment. If undetected root parasites were preventing normal growth in the unsterilized soil, then a small addition of unsterilized soil to the sterilized soil should introduce such parasites and serve to produce a growth depression corresponding to that in the unsterilized soil alone. On the other hand, if the improved growth in sterile soils were to be attributed to a greater solubility of nutrients, biological release of ammonia, etc., the increase in growth would be expected to be somewhat progressive with an increasing proportion of sterilized soil.

As another phase of this experiment, pots were filled with sterilized soil at one side and unsterilized soil on the other (a board partition dividing the interior until the soils were in place). In another series of pots in the experiment it was sought to demonstrate that the improved growth and mass of fine rootless characteristic of sterile soil were a response to nutrients and that the effect could be duplicated with fertilizers. These soil experiments were installed July 28, 1931.

The soil for the experiment consisting of thirty units was collected from the same locality at Makiki as that used by Webster in his experiments mentioned above. The soil was screened and thoroughly mixed. One-half was steamed 3 hours at 25 pounds pressure. H 109 cuttings from Field 15 at Makiki were planted in the various units, the treatments of which are shown in Table II.

TABLE II

Pot Numbers	Treatment
1 – 2	Unsterilized soil.
3 – 4	Sterilized soil.
5 – 8	Sterilized soil in one side of pot; untreated soil in other side.* Two seed pieces planted across the contact plane of the two soils.
9 – 10	Sterilized soil fertilized with nitrogen, phosphate and potash.
11 – 12	Unsterilized soil fertilized with nitrogen, phosphate and potash.
13 – 14	Sterilized soil fertilized with ammonia.
Root boxes, numbers	
17 – 18	Unsterilized soil.
19 – 20	" " 9/10†, Sterilized soil 1/10
21 – 22	" " 7/10, " " 3/10
23 – 24	" " 5/10, " " 5/10
25 – 26	" " 2/10, " " 8/10
27 – 28	" " 1/10, " " 9/10
29 – 30	Sterilized soil.

*The soils were separated by a board partition until the pots were filled; the board was then removed.

†Parts by volume, mixed and placed in boxes.

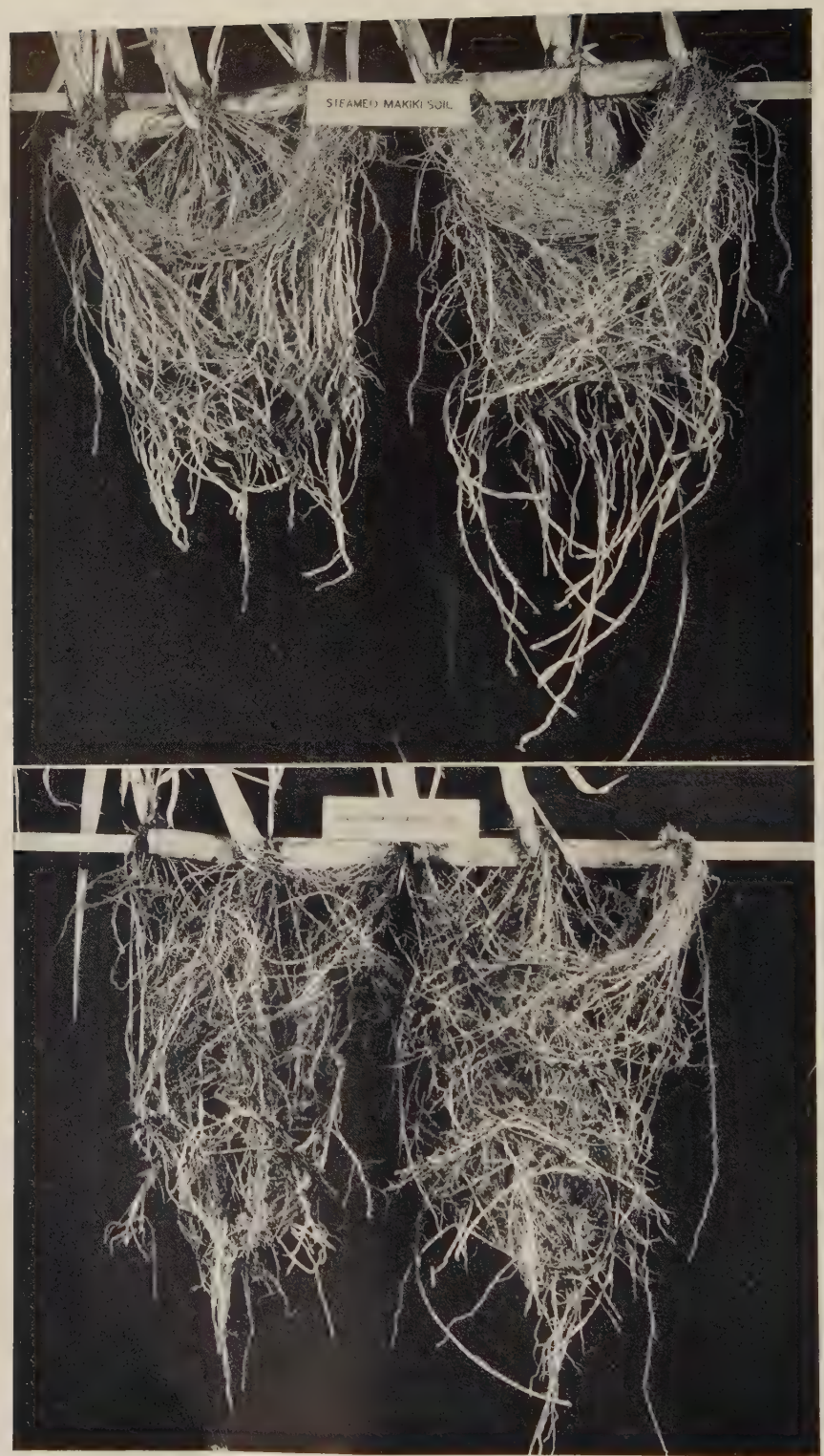

Fig. 1. Root systems of H 109; above, in steamed Makiki soil; below, in natural Makiki soil.

Fig. 2. Root systems of H 109; above, steamed soil fertilized with nitrogen, phosphate and potash; below, unsteamed soil, similarly fertilized. Compare with Fig. 1.

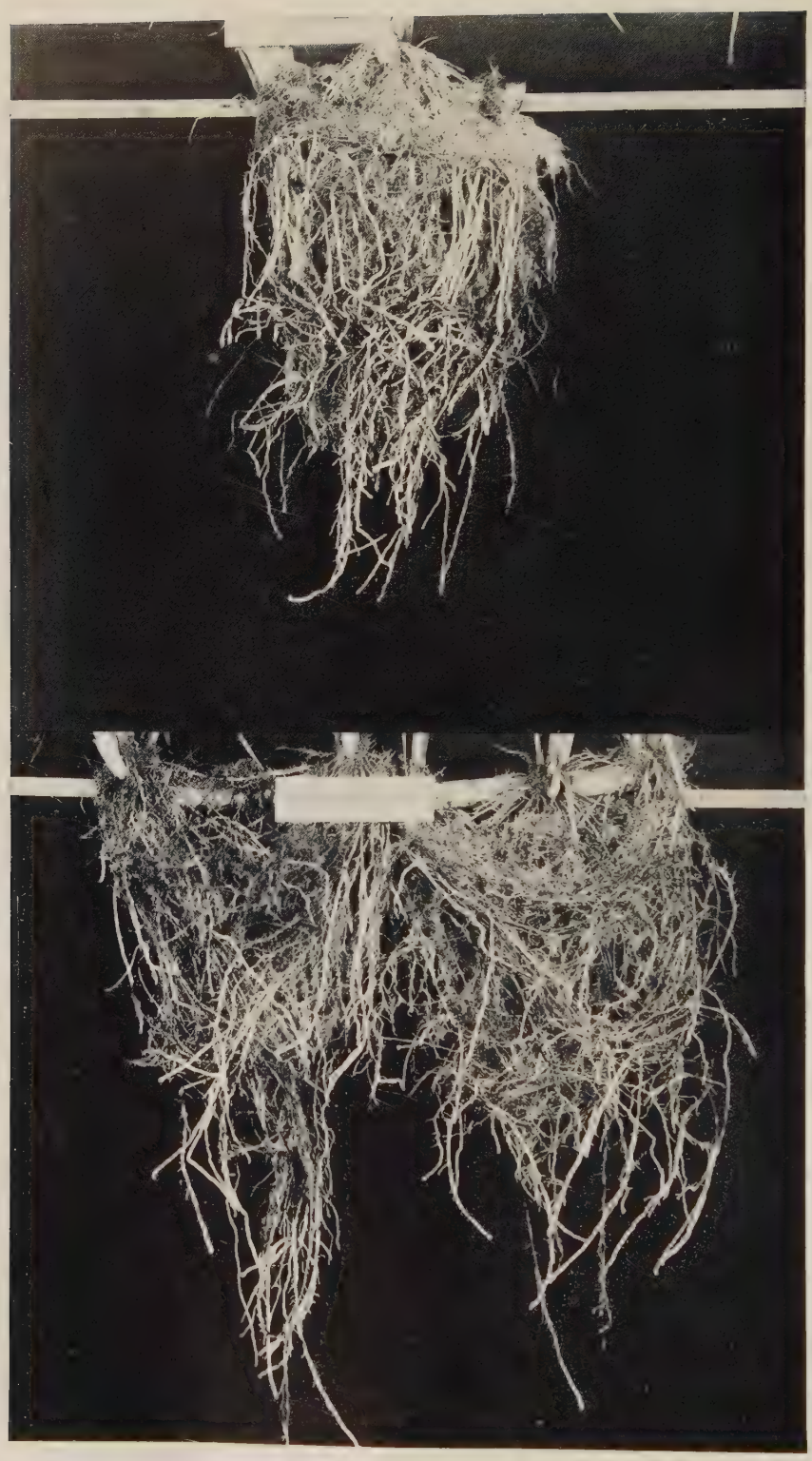

Fig. 3. Root systems of II 109; above, in steamed soil fertilized with ammonia; below, natural soil fertilized with ammonia. Compare with Fig. 1.

The root systems were exposed after 2½ months by washing out the soil. Mr. Van Zwaluwenburg joined in the inspection. Observations and deductions from the experiment may be summarized as follows:

Unsteamed Soil: The plants in unsteamed and unfertilized soil grew comparatively slowly and at the conclusion of the experiment were small, with pale green leaves. The root systems were comparatively small, with few fine rootlets. The roots appeared healthy. (Fig. 1.)

Steamed Soil: The plants in steamed soil were superior in size and color to those in the unsteamed soil. They were about as large as any plants in the fertilized soils but the leaves were not as deep green in color. The root systems were much superior to those in the unsteamed control soil, with conspicuously large white main roots and masses of fine rootlets. (Fig. 1.)

Sterilized and Unsterilized Soil, Fertilized: Some of these pots received a total of 25 grams of complete fertilizer (B 9 = 11 per cent or 2.75 grams nitrogen, 6 per cent or 1.5 grams phosphoric acid [P_2O_5], 6 per cent or 1.5 grams potash [K_2O]). Those fertilized with ammonia received five applications of one liter of water containing ammonia equivalent to a total application of about 7.5 grams of nitrogen per pot. As noted above, the foliage of the plants in fertilized, unsterilized soil was a darker green than that of the plants in sterilized soil, unfertilized, and the plants appeared somewhat more vigorous. The root systems were comparable with those in steamed soil and of about the same habit, but possibly had somewhat less fine rootlets. (Figs. 2 and 3.)

The characteristic mass of fine rootlets commonly observed in sterilized soils corresponding to those seen where cane is grown in water for a long time without added nutrients (p. 332 and Fig. 26) appears to be the result of growth in dilute solutions of nutrients. In sterilized soil this might be attributed to the gradual liberation of ammonia in very small amounts throughout the soil mass as a result of the entrance and activity of biological factors. Russell and Petherbridge (47, p. 257) stated that under the conditions of their experiment dilute solutions of ammonia enhanced the germination of seed.

Where ammonia or nitrate are added as nutrients to soils the root system takes on the character of larger roots, comparatively few in number or sparsely branched. In dilute nutrient solution or in water, many long, hair-like rootlets form apparently as a result of the low concentration of nutrients. Just as the aerial parts of plants become attenuated in weak light, so the roots appear to draw out in hair-like form as a result of a deficiency of essential elements. (Fig. 26.) The opposite happens as well-nourished cane stools increase in size, a fact reported by Venkatraman and Thomas (57). The roots from the cyme rings or root bands of the planted cuttings start out small, the tips increasing somewhat in size with increasing length. The primary roots from the bases of the first shoots, while larger than the roots from the cuttings, are relatively small in the young cane stool. As the stool increases in size and vigor of growth in rich soil, the primaries from the successive suckers are of increasing size and the distal absorbing portions and tips may increase further in size as they extend themselves in the rich soil, until they may be nearly as large as a pencil.

Fig. 4. Root system of H 109. Left half of roots developed in natural Makiki soil; right half in steamed Makiki soil. Note the dense mass at right with matted hair-like rootlets.

It seemed obvious that the improved top growth as a result of steaming the soil had been duplicated in the unsteamed soil by fertilization. Differences of root habit were of degree rather than of type. In other experiments it was significant that noticeable improvement of growth did not occur in fertilized soil as a sequel to steaming. In other words, as Russell has remarked, if the soil is amply supplied with nutrients, particularly nitrogen, steaming it will not serve to materially increase plant growth.

In the sterilized soils mixed with increasing amounts of unsterilized soil, there was a marked decrease of growth where 50 per cent or more of unsterilized soil was present. Less than this amount had no appreciable effect. The tops and root systems indicated that there was ample food present or gradually being elaborated in the sterilized soil to tolerate a 50-50 dilution with unsterilized and potentially less fertile soil, but that a greater dilution reduced the available or potentially available nutrients to the approximate condition of the unsterilized soil.

This behavior is incompatible with the root parasite theory; i.e., that these parasites are responsible for the lesser growth in unsterilized soil. We would expect small amounts of unsterilized soil to infect the sterilized soil and be as harmful as large amounts. If protozoa, which destroy the beneficial bacteria, were introduced with the unsterilized soil, we would expect a similar result but somewhat delayed since these organisms would be limited at first by bacteria for food.

The theory that growth increase is due to the elimination of root parasites is again negatived by the root habit of cane planted across the dividing plane of sterilized and unsterilized soil in the same containers. In these pots, a thin board cut to fit the contour of the pot was placed vertically, dividing it into halves. Steamed soil and unsteamed soil were poured simultaneously into the respective halves of the pot. The position of the dividing plane was oriented and marked on the outside of the pot before the board was removed. Two three-eye cuttings of sugar cane were planted across the dividing plane of the two soils in each pot.

When the soil was washed from the roots, it was noticeable that the roots in the unsterilized soil were comparatively lacking in fine rootlets in contrast to those present in the sterilized soil. (Fig. 4.) It appeared that the roots in the sterilized portion had developed much more extensively as a result of some factors not present in the untreated soil. If we assume harmful factors such as parasites to be present in the unsteamed soils, it is difficult to explain their failure to migrate into the sterilized soil. If we assume the presence of protozoa, which destroy beneficial bacteria (ammonifiers), it is equally difficult to understand why there was no indication of their migration. There was no physical barrier, the two soils being in intimate contact.

Turning again to the hypothesis that growth improvement in sterilized soil is due to an increase of available nutrient, the phenomenon may consist of an initial increase due to the sterilization agents and/or a progressive increase due to changed biological balance, elimination of protozoa and the resulting ascendancy of a population of beneficial organisms, e. g., ammonifying and nitrifying bacteria. The dominant theory advanced by investigators seems to be that growth response in sterilized soil is due to increases of ammonia and an increased solubility of organic matter and that, in addition, with a reduced competition for the nutrients

due to a changed biological activity, the plant obtains a larger proportion. When the sterilization is brought about by steam, we would expect some increased solubility of nutrients and other profound chemical and physical changes as a direct result of heat. Since fumigation with such diverse chemical compounds as chloropicrin, carbon bisulphide, toluene or formaldehyde, for examples, produces a similar improvement, an initial increased solubility of nutrients seems illogical. Considering this phase of the problem, a progressive increase in availability of nutrients (liberation of ammonia) as a result of biological activity seems more logical (see p. 290 *re* suppression of Protozoa).

At first glance, it might appear that the biological theory of increased availability of one or more nutrients as the result of a predominance of such beneficial organisms as Nitrobacter, Nitrosomonas (ammonifying and nitrifying bacteria, etc.) offers a plausible explanation. However, considerations difficult to harmonize with this viewpoint are not lacking.

For example, in the above experiment, where steamed and unsteamed soil were mixed, the biological balance might be assumed to be changed favorably in the former by the treatment and in the unsteamed soil would be presumed to remain unchanged. Now, if these soils be mixed thoroughly in the proportion of equal parts, we would expect the biological factors of each soil to be modified by the other. The mixture, unless initially made richer as a direct result of the steaming of half of its content, should have as the result of changes in biological balance, half of the "stimulating" effect of steamed soil and half of the "depressing" effect of unsteamed soil. Yet this half-and-half mixture grew plants and root systems comparable with those in sterilized soil alone.

It is difficult to imagine a visible soil improvement, as evidenced by enhanced plant growth over a two-month period, to be the result of a changed biological balance when all factors for a readjustment of the balance to the original condition may be presumed to be present from the time the soils were mixed. On the contrary, if the effect is considered to be due to an immediate increase of available nutrients as a result of steaming *per se,* how shall we interpret the improved growth obtained either with chloropicrin or formaldehyde?

Therefore, it was important to know whether the improvement factor which enhances plant growth is present *in toto* immediately after steaming a soil or if it is gradually evolved and as gradually becomes available as a plant stimulant. Quoting from Carpenter (18, p. 31):

> Since ammonia was indicated in the above studies as the chief source of the increased growth, an experiment was conducted in cooperation with F. Ray Van Brocklin, associate chemist, to determine the changes in amount and forms of nitrogen occurring in soil following steam sterilization. Sufficient Makiki soil was screened to fill four crocks. Two crocks of soil were steamed at 15 pounds pressure, for three hours. One crock of steamed soil and one of natural soil were then analyzed by Mr. Van Brocklin to obtain information on the forms of nitrogen, and indications of any change due to steaming *per se.* Duplicate crocks of steamed and unsteamed soil were incubated from July 12 to August 29, 1932, in a moist condition, for the purpose of determining the changes in forms and amounts of nitrogen, incident to biological action. The second series of soil was then analyzed by Mr. Van Brocklin.

The analytical data obtained by Mr. Van Brocklin are summarized by him as follows:

	Analysis immediately after sterilization	Analysis after 6 weeks' incubation
	Total nitrogen (dry basis)	
Natural	1220 p.p.m.	1270 p.p.m.
Sterilized	1230 p.p.m.	1280 p.p.m.
	Ammonia nitrogen (dry basis)	
Natural	16.4 p.p.m.	5.9 p.p.m.
Sterilized	27.6 p.p.m.	40.9 p.p.m.
	Nitrate nitrogen (dry basis)	
Natural	17.3 p.p.m.	17.4 p.p.m.
Sterilized	10.8 p.p.m.	7.0 p.p.m.

Mr. Van Brocklin commented on these analyses as follows:

Any apparent increase in total nitrogen in the soils after irrigation treatment may or may not be real. It may be due to the multiplication of error in calculations from analytical data, the latter not necessarily ultra refined.

However, with the ammonia nitrogen and also the nitrate nitrogen the difference is great enough to be real. In the natural soil there seems to be a falling off in the amount of the former form after incubation in moist condition, while in the sterilized soil there is an increase under similar treatment. The reasons for these differences may be assumed, but further investigation is necessary for actual proof.

With respect to the nitrate nitrogen, the amount seems to be constant in the natural soil, but a loss is indicated in the sterilized soil after periodic watering.

Mr. Van Brocklin also performed citric soluble analyses on Makiki and Kailua soils, steamed and natural, immediately after treatment, and of similar units both planted and unplanted, after a period of approximately three months. There appeared to be no significant change in the content of the citric soluble nutrients, silica (SiO_2), lime (CaO), potash (K_2O), and phosphoric acid (P_2O_5), either as a direct result of steaming or cumulative after incubation of the steamed soils.

Though improbable, it is not to be overlooked that the similar beneficial effects of steaming and chemical fumigation on plant growth may not be due to exactly the same causes (31).

The unused portions of the four soil samples analyzed by Mr. Van Brocklin were used for an observation test and planted with Guam corn and soy beans. The latter were included for observation of response to sterilized soil since the statement was made in one of the Rothamsted reports that all plants except legumes show improved growth in steamed and fumigated soils.

Sixteen small terra cotta pots were steam sterilized and four pots filled with each of the four soil samples respectively which had been analyzed previously by Mr. Van Brocklin. Four seeds of Guam corn and four of soy beans were planted respectively in each of two pots of each soil. (See Table III.) All of the seed germinated and all but one seedling per pot was rogued soon after germination.

TABLE III

Soil Sample	Previous Treatment	Plant
1	Steamed three hours; analyzed the following day; remainder retained in dry condition until Sept. 10, 1932.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.
2	Natural soil, control on 1, kept dry until Sept. 10, 1932.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.
3	Steamed the same as sample 1, incubated in moist condition six weeks before analysis.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.
4	Natural soil, incubated in moist condition six weeks before analysis.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.

Fig. 5. Soy bean plants in duplicate series.
First pair grown in steamed Makiki soil, incubated dry before planting.
Second pair grown in natural Makiki soil, incubated dry before planting.
Third pair grown in steamed Makiki soil, incubated wet before planting.
Fourth pair grown in natural Makiki soil, incubated wet before planting.
Note evidence of depressed growth in the first pair.

The following summary of observations made when the plants were 1½ months old, is quoted from an unpublished progress report dated October 25, 1932:

1. There was marked improvement in the growth of the corn seedlings in the steamed as compared with the unsteamed soil in the samples held dry as well as in those incubated in moist condition. In the steamed soil the growth was noticeably more vigorous in the soil which had been incubated in moist condition in contrast to the soil steamed and held in dry condition.

2. The soy beans showed no such improved growth in the steamed soils. On the contrary, those in the steamed soil which had been incubated dry soon showed evidence of distress (Pots 1 C, 1 D). The symptoms manifested were chlorosis of the leaves and depressed

Fig. 6. Guam corn grown in soils treated identically with those in Fig. 5. Note response to steamed soil in the first and third pair.

growth for a period of about two weeks, at which time a new series of normal green leaves developed at the top. The lower leaves remained chlorotic, yellowed and irregularly spotted with brown. None of the other series of soy beans showed any deviation from normal. At this time the soy bean plants in all series were uniform in size, those with the chlorotic lower leaves being a trifle more spindling in growth habit. All were developing fruit.

3. Mr. Van Brocklin's report shows that in the soil analyzed immediately after steaming nitrate nitrogen was reduced from 17.3 p.p.m. to 10.8 p.p.m. and ammonia nitrogen was increased from 16.4 p.p.m. to 27.6 p.p.m. In the steamed soil, incubated six weeks in moist condition, a further increase of ammonia nitrogen to 40.9 p.p.m. was found while the natural soil showed a reduction from 16.4 p.p.m. ammonia nitrogen to 5.9 p.p.m. The nitrate nitrogen in the natural soil incubated moist remained constant while in the steamed soil similarly treated the amount was further reduced from 10.8 p.p.m. to 7.0 p.p.m.

We may infer from the temporary poor growth of the soy beans in the steamed soil which had been incubated dry, in contrast to the normal growth in steamed soil incubated in moist condition, that some product harmful to this plant is formed in soil by steaming. This harmful product is dissipated in about two weeks when the soil is wet.

The photographs, Figs. 5 and 6, were taken November 26 when the roots were examined after the experiment was concluded. They were not taken at a suitable time to show the depressed top growth of the soy beans, or the most marked increase in growth of the Guam corn in steamed soils. The growth in the various units had become more uniform as the better plants had reached a maximum size for the pots and the weaker plants had gradually caught up. However, the increased root growth of the Guam corn in steamed soil and the weaker root system of the soy beans in the sterilized soil, incubated dry, was still evident as shown in Figs. 5 and 6.

The experiments conducted at the Experiment Station by Webster and the writer regarding the causes of improved growth of cane in sterilized or fumigated soils indicate that this growth response is due to increased liberation of ammonia. Just how this is brought about is not clear. The conclusions of Russell and his associates after a thorough study of various phases of the subject extending over several years are the most logical (see p. 289).

Abnormal Nutrition as a Factor in Pythium Root Rot of Cane

An attempt was made in 1928 to develop a suitable working theory for research concerning the controlling factors of *Pythium* root rot. We knew that the fungus concerned was of general occurrence even on varieties which seldom showed distress. An explanation of the erratic occurrence of growth failure was needed. Our records extending over a period of more than thirty years were searched meticulously, keeping in mind a selected group of the observations which appeared more significant. Finally, a theory of excess of nutrients or unbalanced nutrition was entertained as possibly applicable throughout the diverse conditions where the disease occurred.

Excess of Nitrogen: The interrelations of the nitrogenous group of nutrients were considered to be the most likely field for first attention. The reasons for selecting the possible influence of an excess of nitrogen, and of unbalanced nutrients, on susceptibility of roots to *Pythium* attack have been discussed already

Fig. 7. Root systems of Lahaina cane grown in virgin soil. 1. Virgin soil. 2. Virgin soil 75 per cent, compost 25 per cent, by volume; serious root rot. 3. Virgin soil 50 per cent, and cane compost 50 per cent; complete destruction of roots, and death of shoots.

with reference to significant observations in our records of Lahaina failure (10, pp. 279-284).

Experiments promptly revealed that in the theory adopted we had a field of research pertinent to the fundamental cause of root rot. The evidence indicated a predisposition of cane varieties to root rot in diverse degrees, associated with certain idiosyncrasies of absorption of nutrients which led in these varieties to susceptibility to *Pythium* attack. It was found that sodium nitrate, in excess, greatly increased root rot of Lahaina cane in sick soils and induced it in normal soils. In virgin soil, Lahaina cane grew normally without root rot, but, following the addition of moderate amounts of cane compost (trash composted with "Adco") *Pythium* root rot became serious. Larger proportions of compost resulted in total destruction of the roots and death of the plants. (Fig. 7.) Later, it was shown that Lahaina grew even better in compost alone, without root rot, than in virgin soil alone, but that root rot was severe in virgin soil mixed with an equal quantity of compost. Curiously enough, H 109 grew better in a mixture of equal amounts of soil and compost, than in either compost, or soil, alone. Quoting from the writer's annual report (16, p. 39):

> The apparent correlation of fertilizer practice, with special reference to nitrogen, and the decline and failure of the Lahaina variety has also been pointed out. That H 109 cane might similarly fail if nitrogen was economical and desirable at greatly increased applications above present practice is indicated by pot experiments.
>
> An experiment has shown that in pathology plot soil where root disease of Lahaina is not ordinarily a factor, rotting of the roots of this cane became serious when nitrogen in the form of sodium nitrate was added to the soil before planting in excess of 60 pounds per acre. In the series which received nitrogen at the respective rates of 40 and 50 pounds, scarcely a trace of root rot was found and then only an occasional root was affected. The experiment comprised duplicate series with gradually increasing amounts of nitrogen from 0 to 300 pounds per acre. It will be recalled that previous to the first reports of Lahaina failure, in the year 1896 or thereabouts, nitrogen was not emphasized particularly as a fertilizing element. Approximately 40 pounds of this element per acre in the commercial mixed fertilizer was possibly an average application. Following the date mentioned, fertilizer analysis became more general and nitrogen fertilization received more and more emphasis. Large increases of nitrogen applied per acre were suddenly made in some instances; significantly so on one plantation where Lahaina failed spectacularly (1910 and thereafter). Although excess of nitrogen for Lahaina in some way induces root rot, the exact relation of this element to the root disease is not clear.
>
> Root rot of E. K. 28 increased rather than diminished in a test with gradually increasing amounts of molasses, applied as a possible corrective amendment to Waipio sick soil. The cuttings were planted after incubation of the amended soil for two weeks. The result was in harmony with previous experiments with Lahaina cane and "molascake" soil amendments. In pot tests, the variety P.O.J. 2878 has shown a resistance to *Pythium* root disease comparable to that of H 109. The growth of this variety in the field at Waipio and elsewhere confirms the above observation derived from the pot experiments of October, 1929.

It was soon demonstrated that cane residues, such as compost, were not essential to the development of increased susceptibility. Not only sodium nitrate but stable manure brought on the same condition. Subsequent experiments showed that the resistance of H 109 roots could be overcome by growing the cane in mixtures of soil with 25 to 75 per cent of stable manure. Root rot of Lahaina was induced in a "healthy" soil by amendments with molasses and press cake, incorporated, and the mixture incubated several weeks before planting. No collapse

of Lahaina roots occurred in soil amended with compost or manure and steam sterilized before planting; heavy amendments with these materials did not *per se* cause root collapse or growth failure. When a Lahaina sick soil (from Olaa) was diluted progressively with a healthy soil, *Pythium* root rot became less severe (15, p. 93). With a half-and-half mixture, marked improvement of root health was observed. In mixtures containing less than 20 to 30 per cent of sick soil, *Pythium* root rot became inconsequential.

As a result of these research skirmishes, it was inferred that the controlling factor accessory to *Pythium* as the active agent of root decay, is the type of root

Fig. 8. Sudan grass grown 21 days in phosphate-fixing soil from Hamakua. Plants shown in Figs. 8 to 12 were fertilized with nitrogen, phosphate and potash, but not sufficiently to insure growth in Hamakua soil, sterilized, comparable with that in Makiki soil. (Figs. 11 and 12.)

growth as determined by stimulative nutrients. Quoting from the writer's annual report for 1931 (17, p. 51):

> The relationship of stimulative nutrients to *Pythium* root disease, demonstrated in pot experiments during the years 1928 to 1930, was further confirmed by the correction of a growth failure area at the pathology plot. The variety E. K. 28 has been induced to grow normally for about one and one-half years where it formerly failed miserably. The normal growth followed the simple expedient of depleting the stimulative soil nutrients. This was accomplished by growing H 109 and H 146 for 15 months without added fertilizer in the same furrows where E. K. 28 had failed. The variety E. K. 28 was then planted again.

Vanterpool and Truscott (56, p. 89) may be quoted, regarding the relation of nitrogen to wheat root rot, as follows:

> Carpenter contends that *Pythium* root rot of sugar cane in Hawaii is enhanced by nitrogenous decomposition compounds of sugar cane factory by-products and by excess nitrate;

Fig. 9. Sudan grass grown 21 days in chloropicrin-treated soil from Hamakua.

also that bagasse or pure sugar cane fibre inhibits the disease. Our greenhouse experiments coupled with the knowledge that the nitrate nitrogen is highest when browning root rot is worst, and that on the stubble crop nitrate nitrogen is low when browning root rot is practically absent, suggest that Carpenter's view may hold for browning root rot of wheat also. This is only suggestive as present results are indefinite and inconclusive; it remains for fertilizer experiments in naturally infested fields to prove or disprove this view.

Walker (58) studied the relation of fertility to the similar disease, *Aphanomyces* root rot of peas. He stated that eight canning varieties were tested in the greenhouse on this type of soil from a heavily infested field. All were severely damaged by root rot which underwent a marked decline on the addition to a portion of the soil of a 500-pound application of 4-16-4 fertilizer.

Pythium Root Rot in Phosphate-fixing Soils: Cooke (20) has reported studies of growth failure of cane in phosphate-fixing soils and the steps in his investiga-

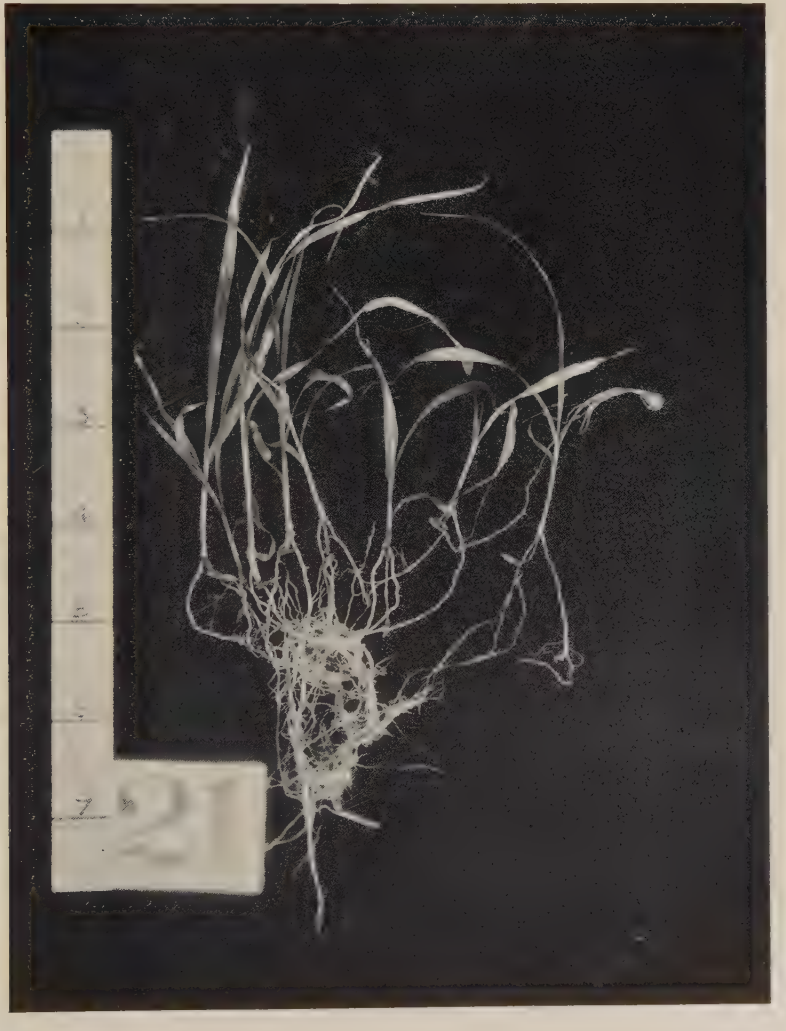

Fig. 10. Sudan grass grown 24 days in steamed soil from Hamakua.

tion which led him to believe that biological factors were concerned. He found that either of two treatments, high phosphate applications or chloropicrin fumigation, gave improved growth of Sudan grass in the phosphate-fixing soils of Hamakua Mill Company. His chemical tests failed to detect any changes of pH of the soil or chemical solubility and availability of nutrients attributable to the action of the chloropicrin. Neither was there any evidence obtained that chloropicrin fumigation of soil resulted in a direct stimulation of plants grown therein. He also pointed out that with normal soil containing adequate amounts of available phosphate, no improvement resulted from chloropicrin fumigation or phosphate applications.

Mr. Cooke's insistence that biological factors were indicated by his investigations led to a more active cooperative endeavor to solve the problem. (Figs. 8-12.)

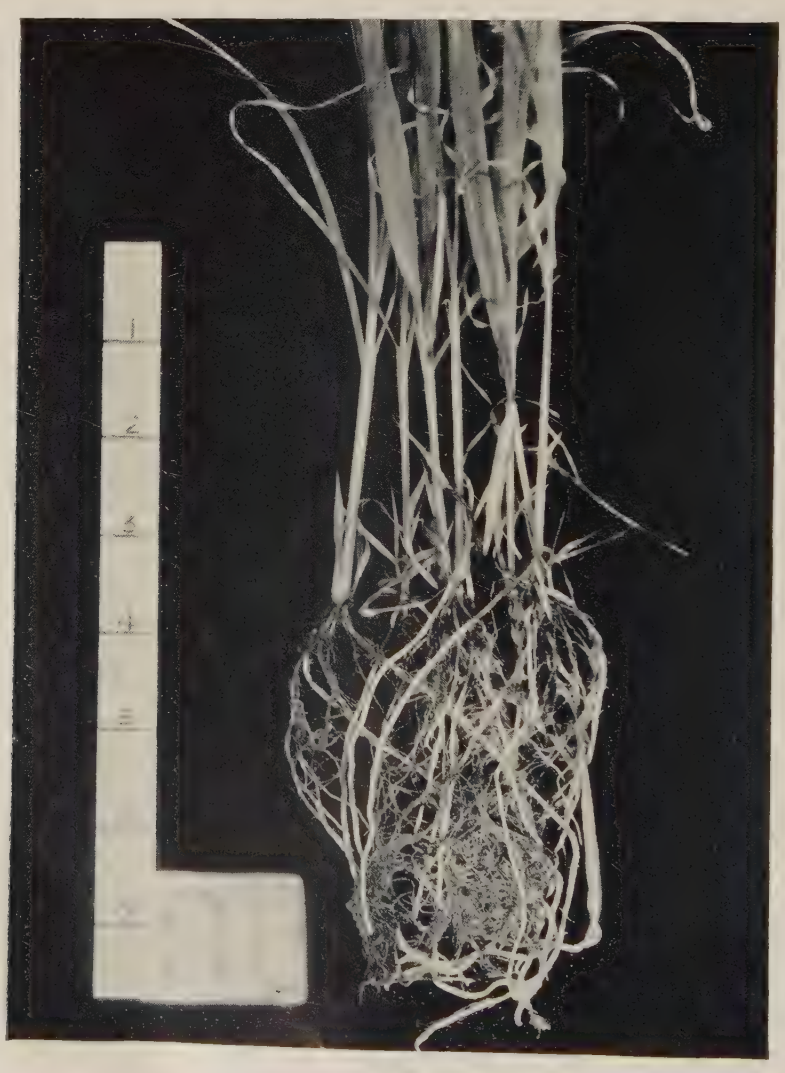

Fig. 11. Sudan grass grown 24 days in Makiki soil.

A dilution test, such as the writer mentions elsewhere in this paper (p. 293), was conducted by Mr. Cooke.

This experiment contained chloropicrin-treated soil and mixtures of treated soil respectively with 1/5, 2/5, 3/5 and 4/5 of untreated soil as well as units of untreated soil. The writer (15, pp. 93, 94) had found similar dilution tests very useful as basic experiments in soil studies to obtain indications whether growth failure problems were biological or malnutritional (excesses or deficiencies). Cooke's (l.c., p. 171) observations of this test are quoted as follows:

> Now, if these pots showed a tendency for quantitative increase from the untreated to the chloropicrin-treated pots, we might expect that the effect on the soil was chemical or physical. This did not occur. Only the pots with all sterilized soil showed a gain. . . . The rest of the pots whether containing 4/5 unsterilized, 1/5 unsterilized soil or all unsterilized soil, showed

Fig. 12. Sudan grass grown 24 days in chloropicrin-treated Makiki soil.

an equal depression in growth. This fact that only 1/5 of the soil being unsterilized could reinfect it and check the growth as effectively as untreated soil, clearly indicated some living soil organism that was destroyed by complete sterilization. A similar test on the subsoil of this field showed exactly the same thing.

As Cooke has stated (l.c., p. 172) the writer found in a preliminary survey of bacteria, fungi and actinomycetes in treated and untreated soil, that the numbers of all three types were greatly decreased by chloropicrin treatment. The number of organisms were not determined again after incubation of the samples.

Examination of roots of Sudan grass in untreated Hamakua soil in Cooke's experiment revealed at once large numbers of oospores and prosporangia of *Pythium* (illustrated in an unpublished report dated April 29, 1933). This fungus was identified from pure cultures as the cane *Pythium,* which we have called *P. aphanidermatum,* but which will hereafter be referred to as *P. graminicolum,* for reasons given on page 288.

The investigation of the "phosphate-fixation *Pythium*-root-rot complex" was conducted jointly with Cooke. It was demonstrated in Mitscherlich pots with both Sudan grass and cane of several varieties that depressed growth resulted when pure cultures of the *Pythium,* isolated from diseased cane roots collected in Hamakua, were added to chloropicrin-treated soil from the same field.

It was also demonstrated by experiments that this depression of cane growth following *Pythium* inoculation of chloropicrin-treated soil, corresponding to that

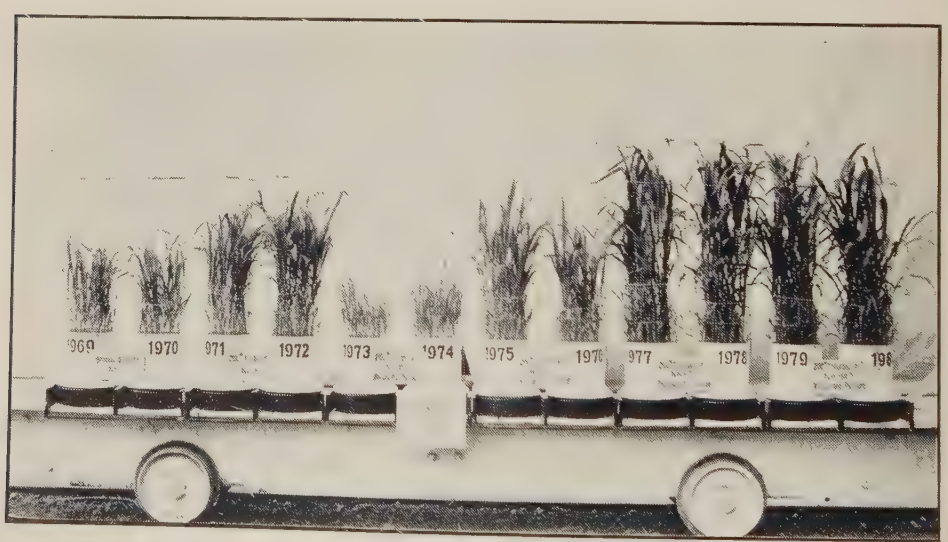

Fig. 13. Test with Sudan grass on soil from Hamakua, Field 26. Reading from left to right—two pots check with N-312, K_2O-426, and P_2O_5-426 pounds per acre; two pots same fertilizer + chloropicrin (200 pounds per acre); two pots same fertilizer + chloropicrin (200 pounds per acre) + *Pythium* sp.; two pots same N and K + chloropicrin and *Pythium,* but 1278 pounds P_2O_5 per acre; two pots same N and K + chloropicrin and *Pythium,* but 2982 pounds P_2O_5 per acre; last two pots same N and K + chloropicrin and *Pythium* but 5960 pounds P_2O_5 per acre. The depression from adding *Pythium* can be seen in pots 1973 and 1974; 1975 and 1976 show that phosphate can overcome the effects of the *Pythium* and especially with the high amounts excellent growth is obtained.

naturally occurring in the untreated soil, could be corrected by heavy applications of phosphate. A discussion of a typical experiment is quoted from Cooke (l.c., p. 173) as follows (Cooke's Fig. 2 is reproduced as Fig. 13):

. . . Mr. Carpenter, using the Mitscherlich pots, was thus able to reproduce the growth failure on chloropicrin-sterilized soil by inoculation with a pure culture of *Pythium*. In an attempt to determine the relationship between high amounts of phosphate and chloropicrin an experiment was also started with the following make-up of treatments and pots.

2 pots usual N-P-K
2 pots usual N-P-K + 200 pounds chloropicrin per acre
2 pots usual N-P-K + 200 pounds chloropicrin + pure culture *Pythium*
2 pots N-K 3P + 200 pounds chloropicrin + *Pythium*
2 pots N-K 7P + 200 pounds chloropicrin + *Pythium*
2 pots N-K 14P + 200 pounds chloropicrin + *Pythium*

Fig. 13 shows this test at the start. The increase when the soil was sterilized with 200 pounds of chloropicrin is apparent. The next treatment shows that when *Pythium* was added, the depression at the beginning was even greater than the original poor growth. This was only temporary, however, because at the end of the test, when 68 days old, the two treatments were almost exactly the same. When three times the usual amount of phosphate is added to this chloropicrin-treated and *Pythium*-inoculated soil the response is practically the same as with chloropicrin. Higher amounts of phosphate up to 21 grams per pot give even better growth.

A brief survey of the fields at Hamakua Mill Company where cane roots were collected by the writer and examined microscopically showed the *Pythium* fungus to be common in the rotting roots where cane growth was depressed. Studies of cane root systems were then conducted in soil from Hamakua in root observation boxes and glass percolation cylinders. (Figs. 14, 15, 16.) The following is quoted from a progress report:

Comparison of the four varieties of cane, U. D. 1, Natal Uba, D 1135 and P.O.J. 36, in chloropicrin-treated and untreated soil from Field 26 K, Hamakua Mill Company: Two kgms. of soil were placed in each of eight glass percolation jars. One cc. of chloropicrin was added to the soil of each of four of the jars, the top of the jars sealed with paper, and fumigation continued for three days. Three days after removing the paper seal, the eight jars were planted in duplicate series of treated and untreated soil with short-joint cuttings of the mentioned varieties. This small experiment consistently provided striking differences in root development and root collapse in untreated vs. treated soil with all four varieties.

All varieties developed a much more extensive root mass in the chloropicrin-treated soil corresponding to the better top growth therein. Root rot of the *Pythium* root disease type was conspicuous with all four varieties in the untreated soil. After about two months, the soil was carefully washed from the roots and the latter examined. The poor condition of the roots and the depressed aerial growth in the untreated soil appeared to be directly due to the root disease. Even the roots which had not collapsed were invaded by the fungus and subject to progressive collapse. P.O.J. 36 appeared to be somewhat less seriously affected than the other three, Natal Uba, U. D. 1 and D 1135. In contrast, the growth of the four varieties in the treated soil indicated that, for the period under survey, in the absence of root rot, sufficient nutrients for normal development were available.

Comparison of five varieties of cane grown in untreated soil and with compost amendments: In experiments several years ago, it was observed that compost amendments tended to aggravate *Pythium* root collapse in soils well supplied with nitrogen. It was thought that the effect of compost on root disease in soils considered deficient in phosphate might be beneficial. The fact that the growth and root health of the varieties, P.O.J. 36, U. D. 1 and

Fig. 14. Cane of four varieties growing in chloropicrin-treated and untreated Hamakua soil, respectively, age two months. From left to right: Natal Uba, treated and untreated; D 1135, P.O.J. 36 and U. D. 1. Note evidence of improved root growth.

Natal Uba, were greatly benefited might have been foreseen, but the reaction of P.O.J. 2878 was surprising. This variety apparently made a normal growth on the unamended soil corresponding favorably with that in 25, 50, 75 and 100 per cent compost. (See Figs. 18 and 19.)

Root study boxes with glass sides were used for this experiment. Soil and mixtures of soil and well-rotted compost were planted with cuttings May 3. The varieties included were U. D. 1, Natal Uba, D 1135, P.O.J. 36 and P.O.J. 2878. One cutting of each variety was planted in each box of a series containing the following items:

1. Soil.
2. Soil 75 per cent, compost 25 per cent, by volume.
3. Soil 50 per cent, compost 50 per cent, by volume.
4. Soil 25 per cent, compost 75 per cent, by volume.
5. Compost.

Fig. 15. Natal Uba and D 1135 grown in phosphate-fixing Hamakua soil. (See Fig. 14.)

1. Natal Uba, chloropicrin-treated soil.
2. D 1135, chloropicrin-treated soil.
5. Natal Uba, untreated soil.
6. D 1135, untreated soil.

Observations from time to time showed that the varieties U. D. 1, Natal Uba and P.O.J. 36 were growing very slowly in the unamended (unfertilized) soil and that this restricted growth (as compared with P.O.J. 2878) was accompanied by badly rotting root systems. D 1135 failed to germinate in the unamended soil. With all varieties except P.O.J. 2878 (and D 1135, which failed to germinate, as above noted) there was a marked improvement in growth in the mixture containing 25 per cent of cane compost, accompanied by much more vigorous root systems. (Fig. 17.) The striking contrast between the depressed growth in the soil alone and the improved growth in the compost mixtures did not appear to be the sole result of differences in available nutrients. The correlation of root health with vigor of the plants appeared to account largely for the differences, especially when considered in contrast with the vigor of P.O.J. 2878 in the unamended soil. (Fig. 18.) This variety seemed to grow normally from the time of germination in the unamended soil and the plants supplied with compost did not grow materially better (Fig. 19). Apparently this variety, not suffering from root curtailment, found sufficient nutrients for its needs either from the cuttings or from the soil.

The soil was washed from the roots about 2½ months after planting. U. D. 1, Natal Uba and P.O.J. 36 were severely affected with root rot in the soil alone. Root collapse of these varieties was of minor significance in the soil plus 25 percent compost. The amount of root failure in D 1135 by comparison in the latter soil mixture, indicated a greater weakness of this variety. Unfortunately, a direct comparison of the D 1135 in amended and unamended soil was not available since this variety failed to germinate in the latter.

The poor growth of U. D. 1, Natal Uba and P.O.J. 36, accompanied by severe root collapse in the unamended soil, considered in comparison with the growth of P.O.J. 2878 with its healthy and extensive root systems, which revealed but traces of root rot, appeared to be directly due to *Pythium* root rot. The fact that P.O.J. 2878 did not benefit materially from the increasing amendments of compost or the compost alone indicated approximately a maximum growth in the unfertilized soil. If we conservatively assume that the growth of all varieties for the period under survey was from the nutrients stored in the cuttings, which were of approximately the same size in the respective varieties, we still have to account for the depressed growth of U. D. 1, Natal Uba and P.O.J. 36 in the unamended soil, in contrast to P.O.J. 2878.

The combined evidence from the experiments thus far considered indicates that the depressed growth—of young cane at least—is due to root rot rather than to any deficiency of available nutrients *per se*. The experiments confirm the program of investigations along the practical lines of variety tests and specific fertilization to increase the resistance of the root systems to *Pythium* root rot.

It was obvious that Sudan grass and young cane plants obtained sufficient phosphate for normal growth in the phosphate-fixing soil after it was treated with chloropicrin. It appeared probable that for young plants, in the absence of *Pythium,* there was sufficient available phosphate in the soil or carried by the cuttings to permit normal development but that in the presence of *Pythium,* there was insufficient phosphate to insure resistance. Mr. Cooke had already grown Sudan grass in cultures in quartz sand treated with chloropicrin vs. untreated sand and was unable to detect any stimulating or nutritional effect of chloropicrin.

Another observation experiment was conducted to note if chloropicrin were merely a sterilizing agent or if it had some direct action on the "phosphate-fixation complex" not possessed by other sterilizing agents. Percolation cylinders were used to grow P.O.J. 36 cane in Hamakua soil, one-eye cuttings being planted, thus limiting the amount of reserve nutrients. The cuttings were hot-water

Fig. 16. P.O.J. 36 and U. D. 1 grown in phosphate-fixing Hamakua soil. (See Fig. 14.)

3. P.O.J. 36, chloropicrin-treated soil.
4. U. D. 1, chloropicrin-treated soil.
7. P.O.J. 36, untreated soil.
8. U. D. 1, untreated soil.

Fig. 17. P.O.J. 36, at left, in unfertilized phosphate-fixing soil from Hamakua; note badly rotted roots. At right, in soil 75 per cent, cane compost 25 per cent, by volume.

treated (52° C. for 20 minutes) and planted September 9, 1933. The experiment included treatments* as follows:

Control					
Chloropicrin	½	cc.	per	kgm.	soil
Toluene	1	"	"	"	"
Carbon bisulphide	1	"	"	"	"
Formalin	3	"	"	"	"
Hydroquinone	0.5	gm.	"	"	"
Steamed soil					

Observations, as well as dry weights of roots and tops showed all treatments superior to the controls. The chloropicrin treatment was duplicated almost to the same degree of improvement by hydroquinone and carbon bisulphide; the toluene, steam and formalin treatments were apparently less effective, or spontaneous infection with *Pythium* occurred to a greater degree. The root growth in the soil treated with hydroquinone was outstanding, the effect apparently being more lasting than with the other chemicals used. The total weight of the superior appearing roots, however, did not equal that in the chloropicrin treatments.

An observation test of the roots of cane varieties in this Hamakua soil was also conducted in glass percolation cylinders. Severed shoots without roots were planted in preference to cuttings, thus reducing the amount and effect of stored nutrients to a minimum. The soil was fertilized with a fertilizing mixture supplemented with sodium nitrate (estimated equivalent to a field application of nitrogen [N] 100 pounds, phosphoric acid [P_2O_5] 200 pounds, and potash [K_2O] 185 pounds per acre).

The amount of root rot observed under the above experimental conditions indicated, in so far as such young plants were a criterion, that the thirteen varieties might be grouped into four classes according to reaction to *Pythium* root rot, as shown in the following table:

TABLE IV

(First 3 weeks' growth)

Susceptible	Moderately Susceptible	Resistant	Highly Resistant
D 1135	P.O.J. 36	P.O.J. 2878	U. S. 996
H 109	P.O.J. 2364	28 - 1234	
U. D. 1		Kassoer	
Natal Uba		28 - 4291	
Badila			
Yellow Caledonia			
	(Subsequent growth—3 weeks to 3 months)		
H 109	U. D. 1	P.O.J. 2878	U. S. 996
D 1135			Kassoer
Badila			28 - 4291
Natal Uba			28 - 1234
P.O.J. 2364			
Yellow Caledonia			
P.O.J. 36			

*All of the mentioned treatments except chloropicrin and carbon bisulphide were used by Russell and Buddin (46), and their characteristics described. Toluene is representative of a class of antiseptics that volatilizes completely, while hydroquinone is representative of the non-volatile antiseptics which persist in the soil and modify biological processes. It was thought that these diverse compounds, in the amounts used, would not all act in the same way to increase the solubility of phosphate if such a reaction by chloropicrin was a tenable theory.

Fig. 18. P.O.J. 2878, in unfertilized Hamakua soil. Compare root system with plant at left, Fig. 17.

Fig. 19. P.O.J. 2878, in Hamakua soil 75 per cent, and cane compost 25 per cent, by volume. Note lack of response to compost in contrast to P.O.J. 36 in Fig. 17.

Additional plants of the same varieties were also grown in root boxes and 4 months later the root systems were washed free of soil and examined. The observations of the root systems confirmed the grouping in Table IV. The roots of U. D. 1 were badly rotted corresponding to those of H 109 in this phosphate-fixing soil (cf. Figs. 20 and 21). Judging by the root systems, the more resistant varieties were as listed in the table, with H 109 and U. D. 1 the most seriously affected and presumed to be the least resistant. In the variety tests in the fields of Hamakua conducted by the Genetics Department, the varieties U. S. 996, 28-4291 and 28-1234 were considered as most promising types.

"Discriminative root nutrition," by which we mean the nourishing of parts of the root system by various essential elements, offers an interesting subject of study. With reference to phosphate fixation and *Pythium* root rot as a factor in growth depression in such soils, it was thought desirable to learn the effect on the root system of supplying phosphate to one root. In preliminary experiments, several units of unfertilized soil and water cultures of cane in which one root of each plant was led into a solution of sodium phosphate were studied (Figs. 22-25). These cane plants, either in phosphate-deficient soil or in water cultures entirely lacking in phosphate were grown with particular reference to root disease and fertilization, e.g., by the briquette method which is under investigation by the Chemistry Department.

It was interesting to note the following points: (1) The isolated roots in solutions of phosphate alone were normal and grew vigorously with many branch roots. (2) The growth of the plants in phosphate-fixing soil was greatly stimulated. (3) The remainder of the root systems apparently suffered less from root rot than the controls with no outside contribution of phosphate. (4) In water culture, the remainder of the root system was stimulated to a much more vigorous development of perfectly healthy roots (Fig. 25); *Pythium* root rot was serious on the control plants which received no phosphate.

Apparently, the phosphate was assimilated by the one root and benefited the entire plant, while conversely the essential elements other than phosphate absorbed by the root mass served to nourish the isolated root. Additional experiments conducted with Hamakua soil in which one root from D 1135 plants (Fig. 23) growing in the soil was led into phosphate solution resulted in improved growth as compared with control plants (Fig. 22) in soil without external contributions of phosphate. With one root conducted into quartz sand containing a fertilizing briquette (Fig. 24) prepared by the Chemistry Department, greatly improved growth of D 1135 occurred in Hamakua phosphate-fixing soil.

Deficiencies, Excesses and Balance of Nutrients: An attempt was made by Mr. Martin and the writer to substitute tap water for distilled water in culture solutions for certain rough determinations where pure water was not required. Martin (36, p. 31), in commenting on this procedure, is quoted as follows:

> The total growth failure of plants in water cultures containing nutrient salts dissolved in tap water (pH value=5.8 to 6) was completely corrected by lowering the pH value of the solution to 5 by adding sulphuric acid. Iron was thus made available to the plants because the increased acidity kept it in solution. In the unadjusted solutions, the young plants developed acute iron deficiency symptoms and soon died. In water cultures made up with dis-

Fig. 20. Roots of U. D. 1 and H 109 grown six months in Hamakua soil (cf. Fig. 21).

Fig. 21. Plants in Fig. 20, transplanted in Makiki soil and grown five months. (Photographed at the same distance.) Note normal roots, in contrast to deficient, rotted root systems in Fig. 20.

tilled water with the same nutrient salts, the pH values of the solution were 5 to 5.2 and the cane plants made a normal growth.

. . . root damage from parasitic fungi, e.g., *Pythium* root rot, is greatly increased in an "unbalanced" nutrient solution. This was particularly true in the plus nitrogen series and in the minus calcium, phosphorus and iron series. These observations are in agreement with the results of soil studies reported by Mr. Carpenter. . . .

Additional confirmation of the relation of nutrients to *Pythium* root rot of cane was observed by Martin (37) in several series of water cultures. The following quotations will summarize his observations on root behavior and *Pythium* root rot as it occurred in solutions deficient respectively in one of the chemical elements essential for cane growth:

Nitrogen deficiency:

The roots appeared to have been stimulated in growth. They attained a much greater length but were smaller in diameter than the roots of the control plants. The root system of each plant completely filled the jar and was extremely free from *Pythium* root rot.

Upon the addition of nitrogen to the minus-nitrogen series, a definite color and growth response was visible within 15 days; it may also be observed that the root system of the H 109 plant . . . lost its compactness following the addition of nitrogen. This condition is due largely to the breaking down of the individual roots from *Pythium* root rot. Carpenter, in 1928, demonstrated that the severity of *Pythium* root rot on cane varieties grown in the soil increases with increased applications of nitrogen. . . .

Iron deficiency:

The roots of the iron deficient plants developed an abnormal type of growth, which later proved to be characteristic of plants growing in a minus-iron medium. The growth of the primary roots was greatly retarded; the secondary roots, as well as those of the third order, were extremely short or "stubby" in growth. A large number of roots were killed by *Pythium* root rot indicating that an "unbalanced" solution is favorable for the development of this disease.

Phosphorus deficiency:

The roots were decidedly brownish in color and were badly affected with *Pythium* root rot. In recent studies it has been shown that cane roots when grown in water cultures deficient in phosphorus are more susceptible to *Pythium* root rot. Cooke and Carpenter demonstrated that sugar cane is much more susceptible to *Pythium* root rot when grown in soils deficient in phosphorus. . . . In soils low in phosphorus, an abundance of fine or hair-like roots develop, the large roots remaining short and small in diameter.

Sulphur deficiency:

The plants in the minus-sulphur series lacked growth and vigor, when compared with the control plants. The depressed growth was marked at the end of 6 or 8 weeks. A poor root system developed on the plants and considerable damage resulted from *Pythium* root rot.

Manganese deficiency:

Shortly after the leaf symptoms developed, the plants failed to make further growth. The leaf and stalk tissues became soft and "rubbery" in texture. Due to this weakened condition, the leaves began to droop and the youngest leaves began to die. The plants, in an effort to continue their growth, developed side shoots but these were also extremely weak. The root systems were in a weakened condition. *Pythium* root rot was present in abundance, and the plants soon died.

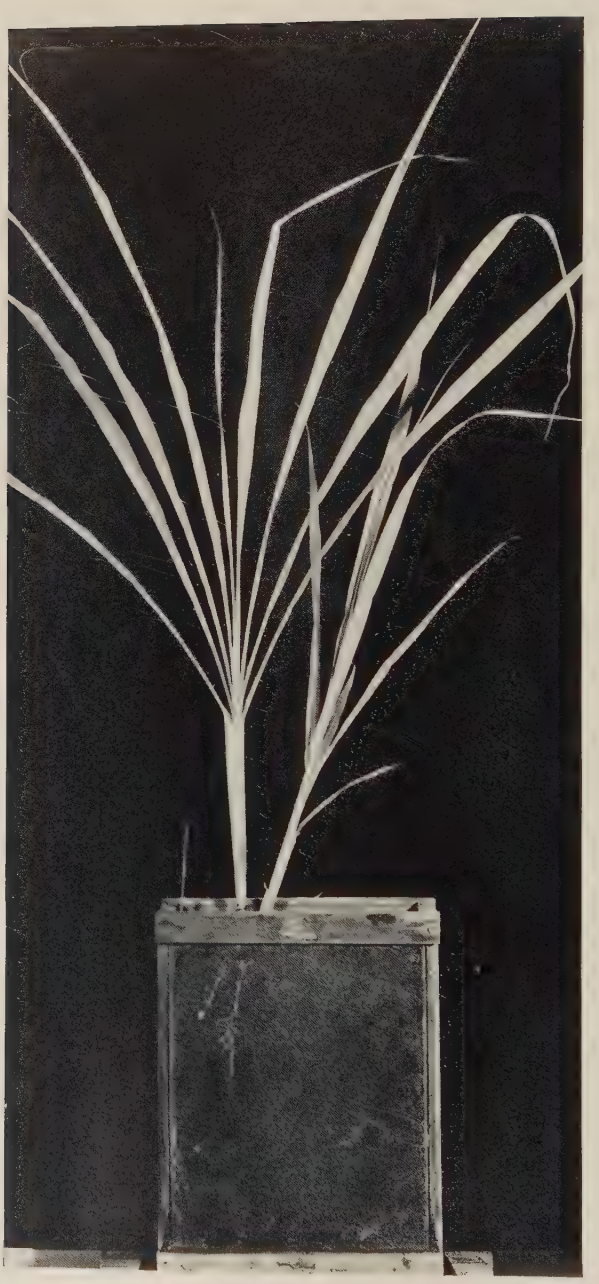

Fig. 22. D 1135 in Hamakua phosphate-fixing soil, control plant for those shown in the following two figures. Fertilized with nitrogen and potash. No outside contribution of phosphate.

Fig. 23. D 1135. Compare with Figs. 22 and 24. One root was detoured into sodium phosphate solution.

Potassium deficiency:

An abnormal root development resulted in this series. The roots were badly attacked with *Pythium* root rot.

Magnesium deficiency:

Considerable root injury resulted from *Pythium* root rot.

Calcium deficiency:

The effect on the root growth was very marked. Root development was greatly retarded in 2 to 3 weeks after calcium had been omitted from the nutrient solution. The roots became soft and flaccid as a result of *Pythium* root rot. At the end of 8 to 10 weeks, the rot was so severe that practically every root had died. The greatest damage from *Pythium* root rot occurred in this series.

Thus, it is seen in water cultures that a deficiency of any of the eight elements, except nitrogen, favors spontaneous *Pythium* attack. The amount of nitrogen even in culture solutions appears to exert a controlling influence on root resistance. A lack of calcium was promptly reflected by root collapse.

Albrecht and Jenny (1) found in a series of experiments that "damping off" of soy beans decreased as acidity decreased and calcium increased. The hydrogen ion concentration in itself was considered unimportant, damping off occurring between pH 3.8 and 6.94. The organisms concerned were not identified.

Swanback and Jacobson (52) made the following statement:

Laboratory and field investigations in Connecticut have shown that a form of brown root rot of tobacco *(Thielavia basicola)* is due to the insufficient intake of calcium by the plant. This condition may be induced by lack of available calcium, an excess of magnesium over calcium, or the presence of appreciable amounts of ammoniacal in relation to nitrate nitrogen.

The variety P.O.J. 2878 has recently been subject to an aggravated growth failure in certain fields at Puuloa, Oahu. The appearance of the stunted plants and the occurrence of *Pythium* in the badly rotting root systems have resulted in a diagnosis of *Pythium* root rot. The cane was growing normally in the lower Puuloa or coral fields but was failing on the slopes of the Salt Lake Crater. We might assume that since this variety is not considered to be sensitive to either nitrogen excess or phosphate deficiency, that the susceptibility may be induced by deficiencies of one of the elements essential for growth, e.g., calcium, iron, etc., mentioned on pages 325, 328. A good response of P.O.J. 2878 to chloropicrin fumigation of the soil in pot studies was obtained and indications of response to small applications of calcium sulphate.

The effect of excesses of the various elements, except nitrogen, in the soil has not received adequate attention. One soil observation indicated that applications of friable coral to a portion of a field in changing a road grade at Kailua Substation brought on *Pythium* growth failure of the varieties Molokai 3978 and 28-4867. The variety 28-1234 did not appear to be checked in growth in this environment.

Determinations made by the Chemistry Department indicated that the pH of the soil had been changed from pH 7 to 8.2 by the treatment. The aggravation

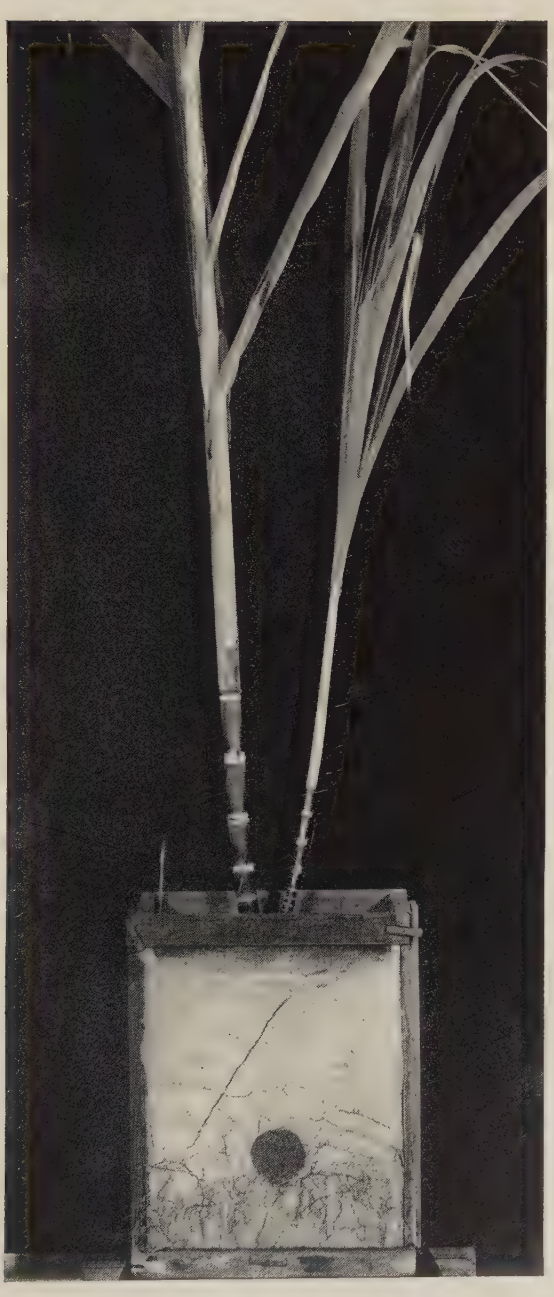

Fig. 24. D 1135. Compare with Figs. 22 and 23. One root was detoured into quartz sand containing "complete fertilizer" briquette prepared by the Chemistry Department.

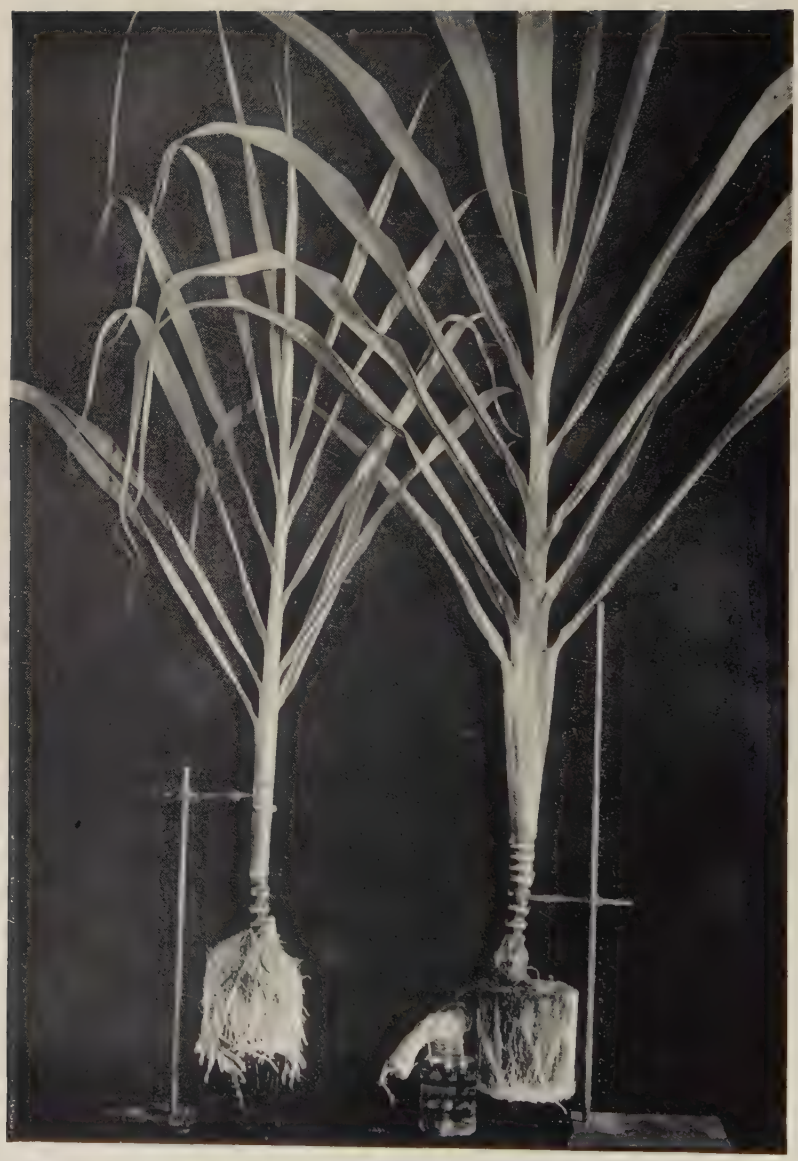

Fig. 25. D 1135. Discriminative root feeding. Both plants in minus-phosphate culture solution, the one at right having had one root in a solution of sodium phosphate for two months. *Pythium* root rot was severe in the plant at left. Phosphate from the one root apparently was sufficient to improve growth and prevent root rot of plant at the right.

Fig. 26. Root masses of P.O.J. 36 and D 1135, developed in three and a half months from short cuttings in tap water without addition of any nutrients. Water changed weekly.

of root rot was possibly due to unbalanced nutrients, and to deficiencies (e.g., of iron) rather than to an excess of calcium *per se*. Earlier pot experiments with soil from Waipio (island of Oahu) in which Lahaina failed consistently showed that applications of finely ground coral rock aggravated the rotting.

A pot experiment was conducted at the pathology plot, Honolulu, with the varieties Molokai 3978 and 31-4867. Soil from that locality was mixed with increasing amounts of calcium carbonate (tailings from Waianae Lime Co.) as shown below and planted with the two varieties. Each pot had about 30 pounds of soil.

Treatment

Calcium carbonate (pounds).....	0	¼	½	2	3
Number pots of each variety.....	4	3	3	3	2

Growth of the variety Molokai 3978 was somewhat depressed even in the check and the depression was aggravated with the increase of calcium carbonate amendment. *Pythium* root rot was increasingly prevalent and correspondingly destructive. No root rot of 28-4867 was observed in the control series nor in

significant amount in any series except the last which contained 3 pounds of lime per 30 pounds of soil. The growth in this series was conspicuously depressed, the leaves yellow and abnormally dry and rolled.

The excellent growth of roots which was obtained in tap water without added nutrients, with fifteen cuttings consisting of five of each of the varieties, P.O.J. 36, D 1135 and Natal Uba, is worthy of mention. The cuttings were placed in tap water May 5, 1933, and the water changed once a week thereafter. The water in three jars of each series was acidified with sulphuric acid to a hydrogen ion concentration of 5.0; the others were left with pH 7.9 approximately. No *Pythium* root rot occurred in the growing period of 3½ months; Fig. 26 shows the remarkable mass of healthy roots which developed. The rootlets were of the fine type Martin reported (37) associated with nitrogen deficiency. Top growth was very slow and the leaves pale green throughout the period. Growth had apparently ceased at the end of about two months.

Martin (36) reports that when detached shoots were grown in standing tap water, a restricted root system was formed. The prevailing difference in root mass between Martin's experiment and the writer's is attributed to the difference in the amount of nutrients available in the cuttings as compared with that in the detached shoots. Martin's and the writer's experiments incidentally supplemented each other and contributed to our knowledge of the elemental factors associated with the development of roots resistant to *Pythium* attack.

The stored food of the cutting, which may be recognized as a balanced ration, has sufficed in this experiment for a moderate top growth and the development of an almost incredible mass of healthy roots. This indicates that "balanced" deficiencies do not lead to root rot and again raises the question as to the effect of balanced excesses of nutrients on the susceptibility of roots to *Pythium*. In other words, can excessive nitrogen, which is conducive to root rot of certain varieties, be balanced and rendered innocuous with phosphate and potash, etc.?

This question has not been thoroughly investigated. Cooke had found that certain phosphate-fixing soils responded to heavy phosphate applications, approximately five times the normal applications used in the Mitscherlich studies. Such large applications were not practicable. It was thought that smaller amounts of phosphate might serve to check the root rot, if the nitrogen supply was at a minimum. Mr. Cooke kindly conducted a Mitscherlich experiment with Sudan grass in "phosphate-fixing" soil from Field 26 K, Hamakua Mill Company, to investigate this point. Four series of eight pots each were included, the nitrogen applications being varied from "N" or standard practice in the Mitscherlich work as follows: ¼ N, ½ N, N and 4 × N; in each series the potash was standard but the phosphate was varied from standard or "P" to include 3 × P, 7 × P and 10 × P. It was soon evident that with less than standard nitrogen (N) application this element was a limiting factor in growth in this soil. There was no indication that the phosphate required to satisfy the soil and become useful to the plants could be reduced below Cooke's empirical "5 × P". The series of dry weights of the plants reported by him showed that the largest yield had been secured with 10 × the phosphate and 4 × the standard nitrogen application (10 P K 4 N) and the next largest 7 P K 4 N.

In the foregoing section of this paper, the theory of the determining influence of abnormal nutrition of the cane plant upon susceptibility to *Pythium* root-rot disease, advanced in 1928, is substantiated by experimental evidence obtained in soil and in water cultures. The clarification of the "root rot" and "growth-failure complex" of sugar cane has advanced rapidly in the cooperative studies with Cooke regarding phosphate-fixing soils. The contributions brought to our attention from time to time by Mr. Martin as *Pythium* root rot occurred in his water cultures, deficient respectively in one of the several elements essential to cane growth, greatly extended the scope of this synthesis. Where growth failure associated with *Pythium* root rot occurs in commercial fields, either a natural varietal susceptibility and/or a susceptibility acquired by abnormal nutrition is to be suspected.

Resume

The literature of the last decade shows an increasing recognition of the causal relation of species of *Pythium* to many obscure diseases of various plants including the grasses, more particularly root rot of sugar cane and of the cereal crops, corn and wheat. Beyond a discussion of the general aggravating effects of high soil moistures and low soil temperatures on the severity of the attack, the literature offers no definite information on the fundamental factors which determine the occurrence of the disease.

An investigation of the erratic occurrence of root rot of Lahaina cane in Hawaii, which finally was largely responsible for the elimination of this popular variety from commercial cane culture, required consideration of other factors than soil types, soil temperatures and moisture. The disease was not restricted to any types of soil, occurring wherever the variety was grown throughout the great diversity of environments on irrigated as well as unirrigated plantations and even on virgin lands as well as soils long in cultivation to cane. It was recognized that both moisture and temperature were of significance to the degree of injury but of secondary importance to factors which determined what particular areas would be affected. Unless increased susceptibility of this variety induced by some determinative factors of the environment other than moisture and temperature was present, the latter factors did not appear *per se* to be very important.

Varieties differed in their behavior to *Pythium* root rot but even the most resistant, D 1135, Yellow Caledonia and H 109, harbored the fungus to some extent so that it was difficult to offer convincing proof that the disease of the popular Lahaina was due to *Pythium* attack. The actual occurrence of the fungus within the roots of a variety considered susceptible did not necessarily result in root rot sufficiently severe to cause growth failure. It was necessary to presume factors which determined whether the rotting was restricted to a few roots, progressed slowly and was inconsequential, or became epidemic and destroyed all the roots as fast as they were formed, resulting in complete growth failure. A theory of susceptibility varying according to soil nutrients was adopted for the investigations. Excessive nitrogen for Lahaina as a prototype was first investigated. It was demonstrated that with applications of nitrogen considered moderate for other varieties, root rot resulted even in soils where Lahaina grew normally with small nitrogen applications. Then it was shown that even the resistant variety

H 109 was severely attacked by *Pythium,* following large applications of nitrogen to the soil. To produce this effect with H 109, nitrogen was required at rates which were decidedly uneconomical and greatly in excess of those which had been found to lower the quality of juice in the cane crop at harvest. Thus, it appeared that our standard variety for irrigated plantations was not likely to deteriorate as Lahaina had done, i.e., to succumb to *Pythium* attack as a result of excessive nitrogen fertilization. The effects of a combination of high nitrogen and low phosphate availability on standard canes sensitive to the latter have not been investigated.

It seems obvious that the ability of H 109 to use nitrogen may be one of the criterions of a superior cane. That its superiority over other seedling canes, first evident at Ewa Plantation, coincident with the use of increasing nitrogen in 1910 and again in 1912, in which this plantation was the pioneer, may have been due to the fact that elsewhere sufficient nitrogen was not applied to bring out its superior vigor. If we disregard root rot, which was a factor in the recognition of H 109 as superior to Lahaina, is the ability to use more nitrogen without detrimental effects in root rot or in deterioration of cane juice a criterion of superior canes? Can we predict without trial that some of these canes which seem to be equal to H 109 would not be superior if the conditions of culture were modified to suit them by the application of stimulative nitrogen beyond the amount which happens to be the maximum for H 109 and injurious to its juice quality?

Experiments at the pathology plot demonstrated that the growth failure factors in this soil for E. K. 28 were corrected by growing H 109 *without fertilizer* for two years, in the same furrows from which E. K. 28 had been removed, to lower the nitrogen content. The plot was replanted with E. K. 28, in the same furrows, and no evidence of growth failure has been observed in the following three years.

Subsequent investigation of the effect of nutrients on root rot has shown that in the phosphate-fixing soils of Hamakua, the fungus is enabled to destroy the roots of commercial varieties such as D 1135 and brings on growth depression; and that the condition can be corrected experimentally by chloropicrin treatment to eliminate the *Pythium* fungus, or by large applications of phosphate. Neither the chloropicrin treatment nor the phosphate applications required are economical for field use. Mr. Martin has shown that in water cultures of cane not only deficiencies of phosphate but also deficiencies of either calcium, magnesium, iron, potash, manganese, and sulphur were accompanied by *Pythium* root rot. Nitrogen deficiency, on the contrary, had the opposite effect of preventing its inception, or checking it in cultures where it was present before the deficiency was brought on.

If we disregard areas of soil where *Pythium* root rot is a factor with certain varieties as a sequel to abnormal nutrition, our crop cane is considered to be relatively free of root-pruning parasites and root-rotting organisms. In general, it is considered that root replacement by normally functioning cane plants as a result of the natural vigor of this crop nullifies the effect of *Pythium* and the minor agents of root destruction in commercial fields. In abnormal soils such as those of the phosphate fixing type and in other soils where excesses of certain chemical elements or deficiencies of those essential to normal growth occur, *Pythium* root rot may be expected to cause, or to aggravate, growth depression. In general,

under such conditions, selected cane varieties offer the economic way to meet the problem in the Territory of Hawaii.

Summary

1. A synthesis of facts obtained during the last few years of research is presented which shows that abnormal nutrition precedes root rot of sugar cane and Sudan grass by *Pythium graminicolum* Subramaniam, formerly called *P. aphanidermatum* (Edson) Fitz.

2. Cane varieties differ in susceptibility to *Pythium* root rot. They apparently differ also in their tendency to, and the resulting effect of, abnormal nutrition. A quality of resistance of certain varieties of cane is changed to varying degrees of susceptibility by modifying the nutritional environment.

3. Nitrogen in excess for the particular variety leads to susceptibility to *Pythium graminicolum* in virgin soil and in soils where the disease is not ordinarily observed.

4. Deficiencies of available phosphate promote *Pythium* root rot and growth failure of canes which are not particularly sensitive to increased nitrogen, and which grow well where Lahaina was a miserable failure and continues to fail in trial plots. H 109, D 1135 and Yellow Caledonia, for example, are particularly sensitive to low phosphate availability. P.O.J. 2878 appears to tolerate either high nitrogen or low phosphate availability. It is susceptible to *Pythium* root rot in certain fields at Puuloa, Oahu, but the accessory factors have not been determined.

5. In the phosphate-fixing soils studied, there is sufficient available phosphate to permit normal growth of Sudan grass, and young cane plants, when *Pythium* is eliminated by chloropicrin fumigation. Reinfection or inoculation of such soils with *Pythium,* after fumigation, induces growth depression. This artificially induced depression was overcome and normal growth induced again by adequate phosphate applications.

6. Martin reported that *Pythium* root rot was serious on cane grown in culture solutions deficient in either phosphate, iron, calcium, magnesium, potash, manganese or sulphur.

7. Experiments indicate that excesses of calcium and probably of the other bases, magnesium and sodium, and of toxic salts of aluminum and iron in the soil, favor root rot. Harmful base ratios and unfavorable balances of nutrients are the probable result, e.g., a deficiency of iron or phosphorus *et al.* The increase of susceptibility is to be considered as due to such deficiencies rather than to any direct effect.

8. Soil moisture and temperature are important factors in determining the degree of severity of root rot when susceptibility of the roots to *Pythium graminicolum* is present, either the natural weakness peculiar to certain varieties or the susceptibility acquired by stronger varieties as a result of abnormal nutrition. Abundant soil moistures and relatively low soil temperatures (70° F. or lower) favor root destruction by *Pythium* while, at the same time, the low temperature restricts root replacement.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 18, 1934 TO SEPTEMBER 4, 1934

Date	Per Pound	Per Ton	Remarks
June 18, 1934	3.025¢	$60.50	Philippines, 3.00; Puerto Ricos, 3.05.
" 19	3.13	62.60	Cubas.
" 20	3.075	61.50	Philippines, 3.05; Puerto Ricos, 3.10.
" 21	3.11	62.20	Philippines, 3.10; Philippines, Puerto Ricos, 3.12.
" 22	3.165	63.30	Cubas, Puerto Ricos, 3.15; Cubas, 3.18.
" 28	3.15	63.00	Puerto Ricos.
" 29	3.1667	63.334	Puerto Ricos, Philippines, 3.15; Cubas, 3.17, 3.18.
July 6	3.15	63.00	St. Croix.
" 18	3.17	63.40	Cubas.
" 20	3.20	64.00	Puerto Ricos, 3.18; Cubas, 3.22.
" 23	3.175	63.50	Puerto Ricos, 3.17, 3.18.
" 26	3.18	63.60	Cubas.
" 31	3.20	64.00	Cubas.
Aug. 2	3.225	64.50	Philippines, 3.18; Cubas, 3.27.
" 3	3.30	66.00	Cubas.
" 7	3.32	66.40	Cubas.
" 10	3.20	64.00	Puerto Ricos.
" 24	3.22	64.40	Cubas.
" 29	2.70	54.00	Cubas.
" 30	2.75	55.00	Cubas.
Sept. 4	2.86	57.20	Cubas.

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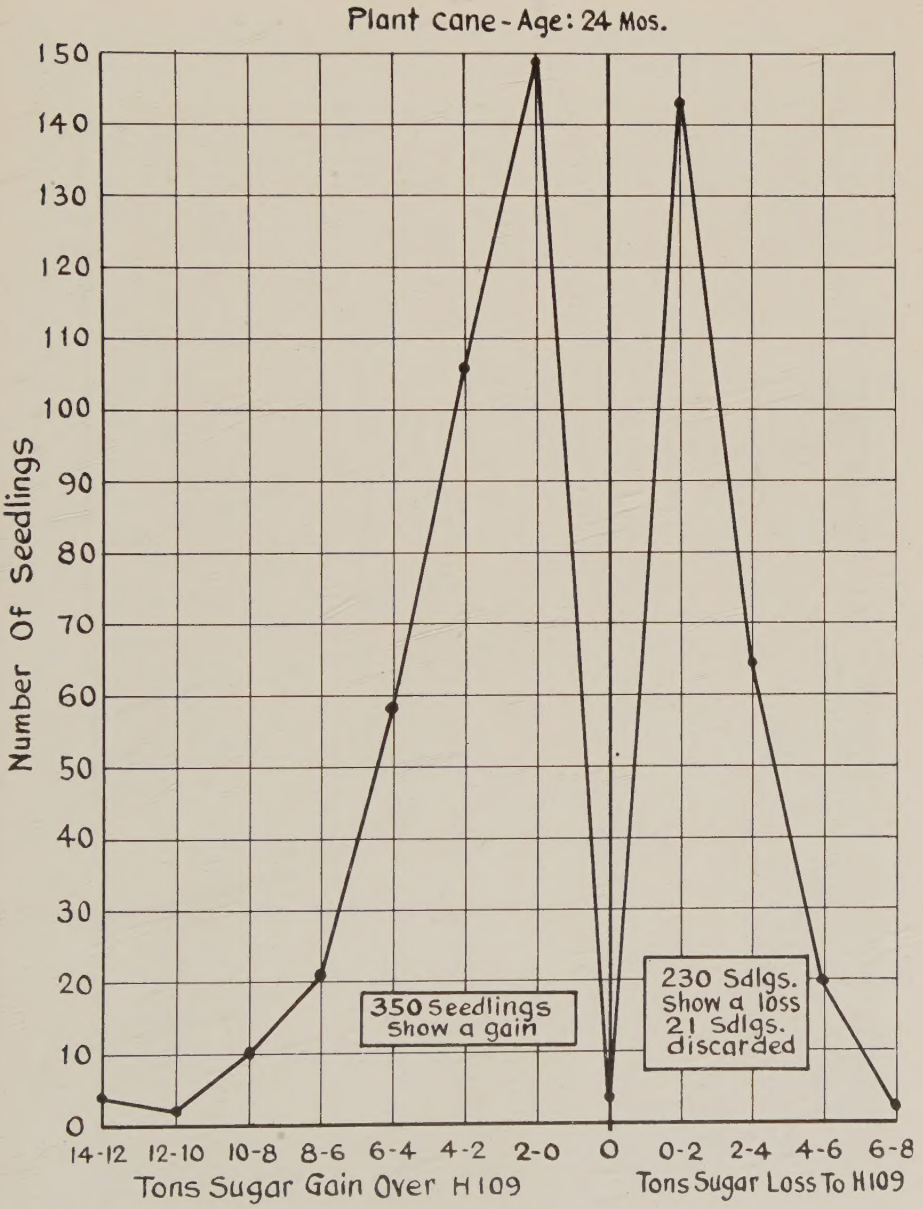
ILLUSTRATIONS APPEARING ON THE COVERS OF VOLUME XXXVIII

FIRST QUARTER

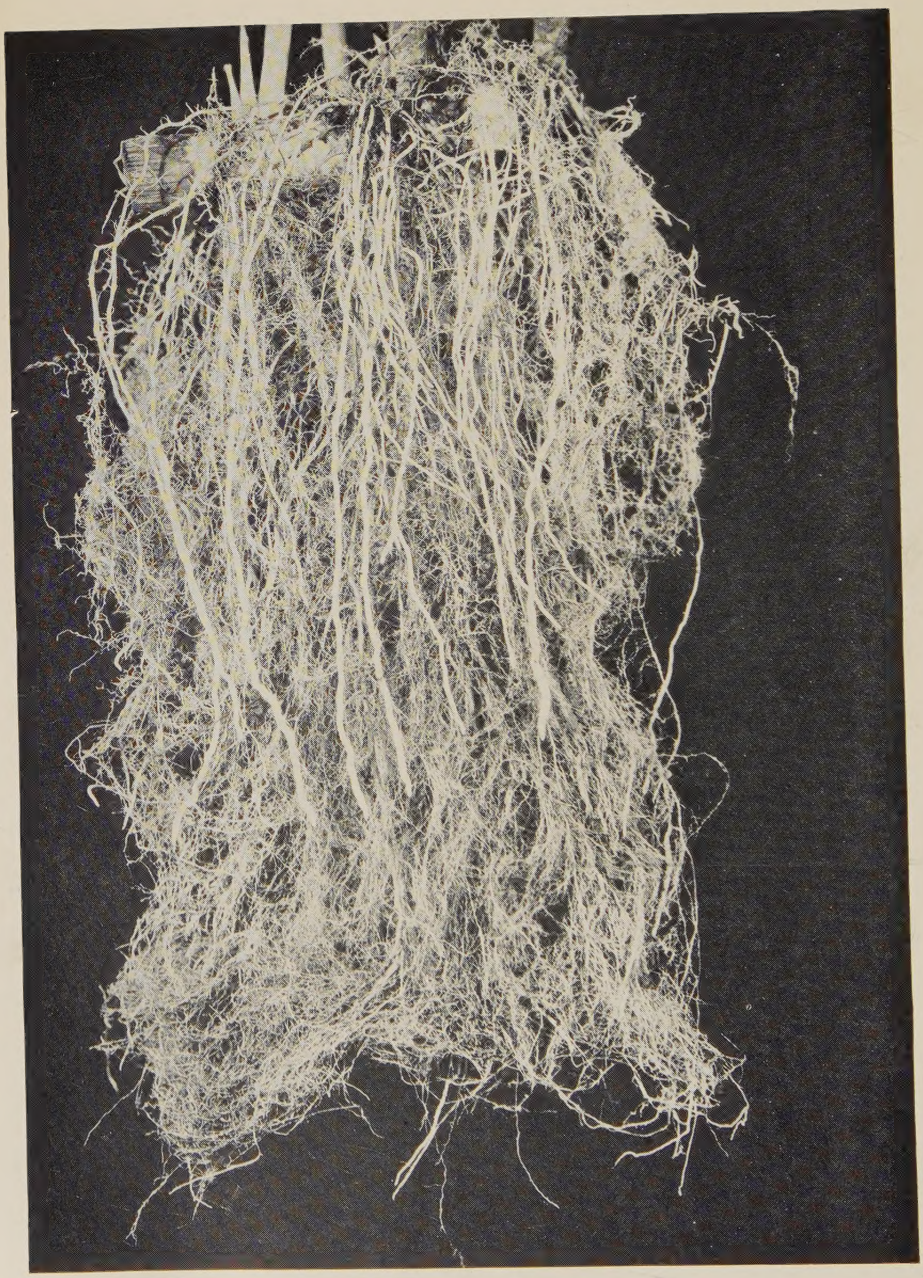
The growth of sugar cane may be studied to advantage in culture solutions. The above photograph shows the normal development of POJ 2878 (extreme left) and H 109 (extreme right) when grown in sand cultures for 7 months and Lahaina (two center plants) when grown in water cultures for 4 months.

SECOND QUARTER

31-1389. A promising new seedling.



This diagram shows the yield performance of 580 seedlings under comparison with H 109 in preliminary trials at Waipio substation. It will be noted that 350 seedlings showed various degrees of superiority over the standard cane while 230 were inferior under these first, single-plot comparisons. Such data do not permit of deductions as to the ultimate worth of the varieties tested, but are of great value in planning tests that will offer more exact comparisons.



Healthy cane roots free from injury by root fungi.